The WELDING JOURNAL

DECEMBER 1954

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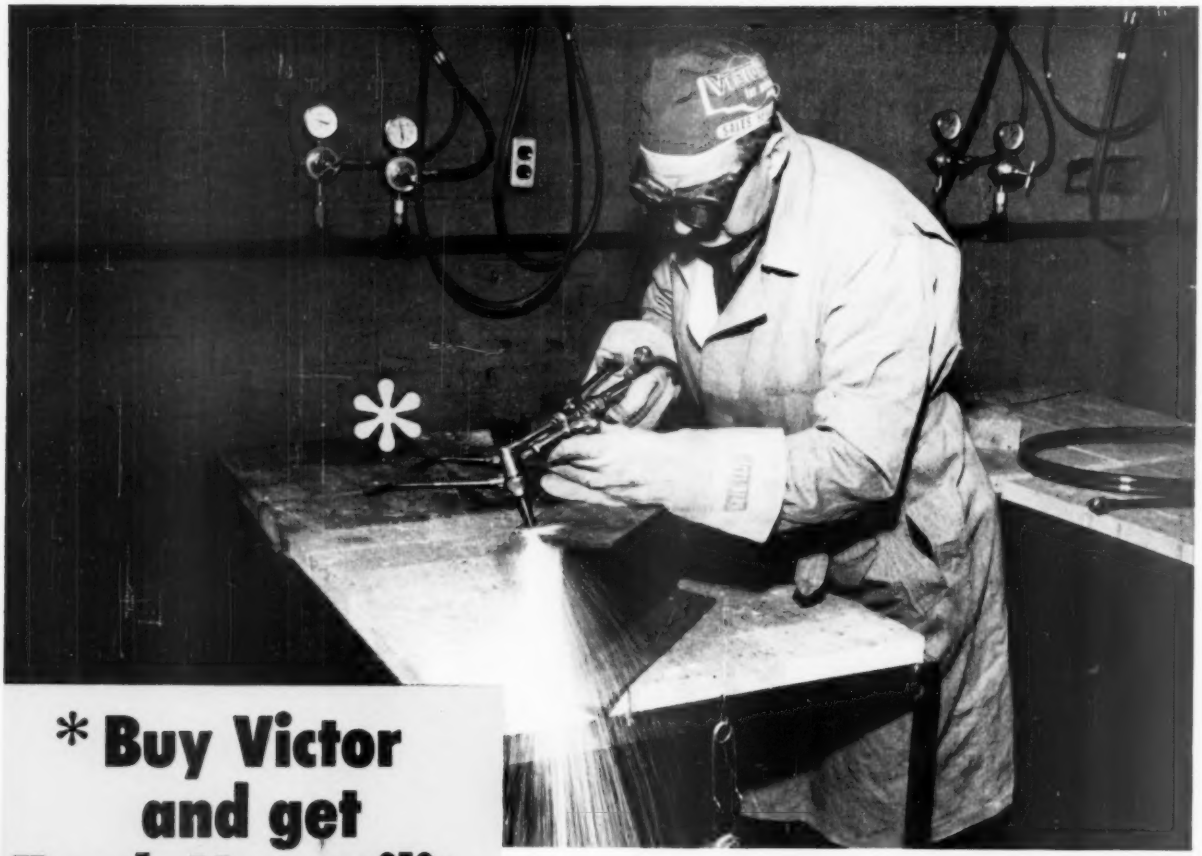

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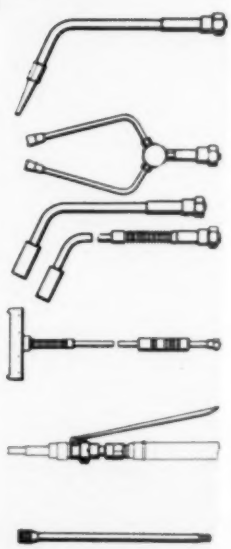

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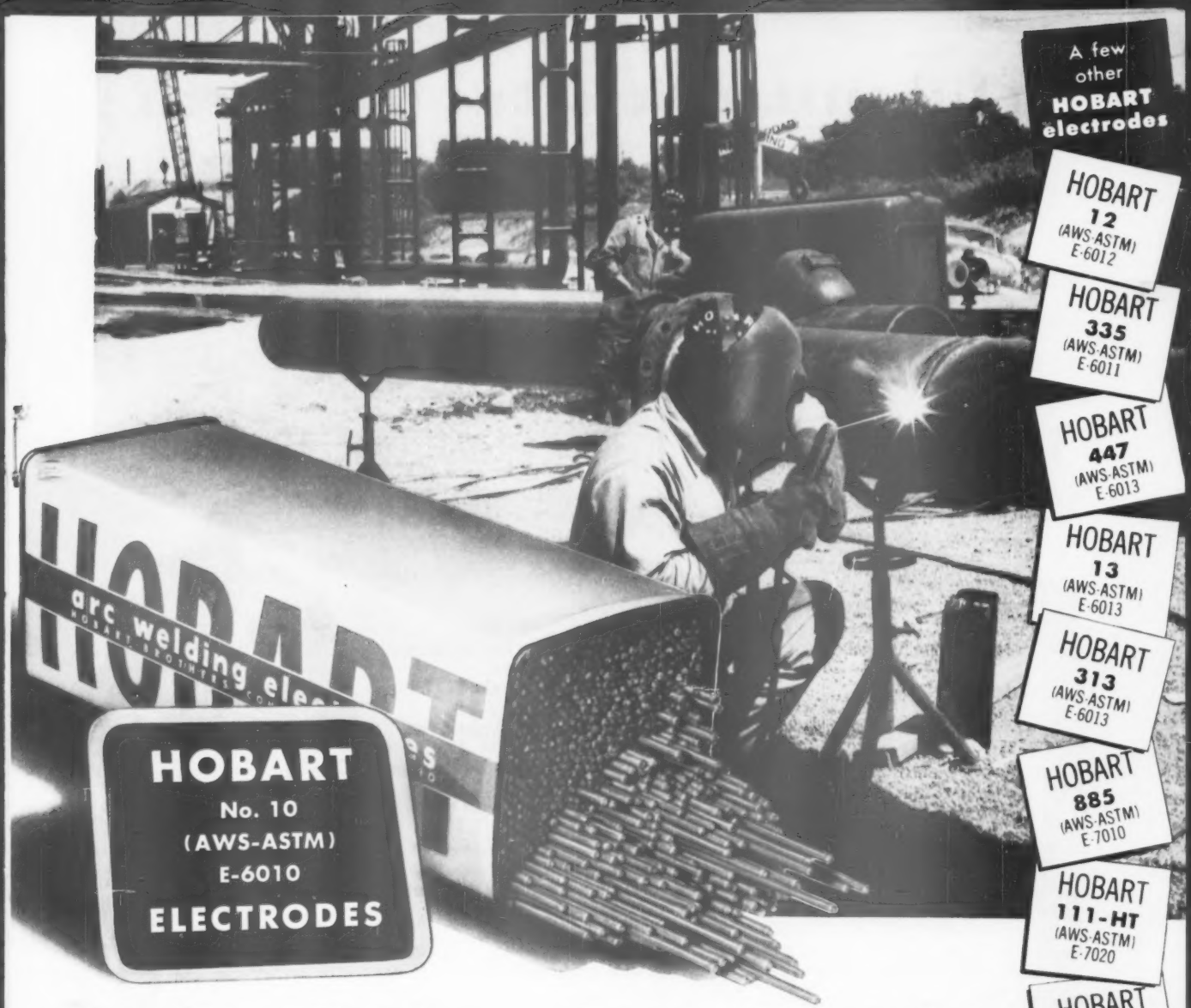

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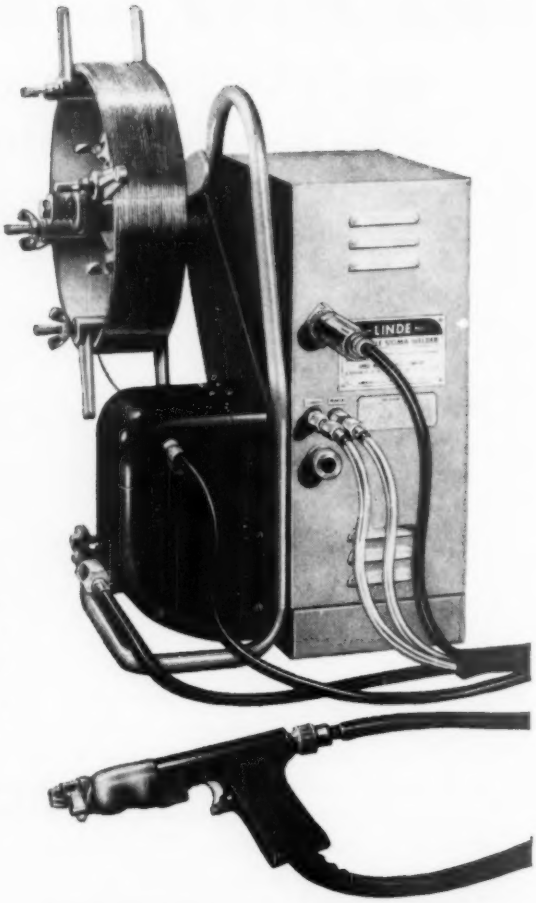

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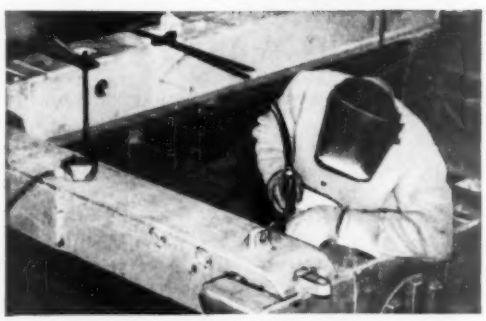

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The WELDING JOURNAL

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The WELDING JOURNAL

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Procedure Control as Applied to Automatic Welding Processes

A review of developments and procedure controls which may be applied to the various welding processes to bring about economical and quality production

by Warner H. Simon

INTRODUCTION

THE development of the welding industry is one of ever changing trends, and in reviewing the pattern of its rapid growth, we find that it has undergone four distinct phases.

First was the humble beginning of welding merely for repair purposes so that welding was solely a maintenance function.

Then secondly came the long arduous struggle which lasted until the late 30's to convince industrialists that here was a process with tremendous possibilities for joining metals. The development of the coated electrode and improvements in manipulation techniques were instrumental in advancing manual welding to a highly skilled process.

After manufacturers and fabricators became aware that welding as a joining process was here to stay, the emphasis shifted to mechanized welding. The development toward mechanized welding, the third trend, got off to a slow start because consistent quality could not be maintained, even with a high degree of operator skill. The inability to control automatic welding with respect to its specific requirements, distinct from other manufacturing processes and manual welding, resulted in a reluctance to accept and utilize automatic welding.

Warner H. Simon is Welding Engineer for Dresser Manufacturing Division, Dresser Industries, Inc., Bradford, Pa.

Presented at the AWS National Spring Meeting held in Buffalo, N. Y., May 4–7, 1954.

We are now in the midst of a fourth trend in which experience is utilized to overcome these difficulties by careful planning and by employing appropriate testing methods which reveal errors arising from faulty techniques. Thus we are designing the welds for a specified quality rating of the product. This trend necessitates the use of specialized testing and research facilities. But such equipment can only be justified provided the plant facilities and the organizational setup will permit their utilization toward the development of fully automatic or controlled welding. This statement bears repeating when surveying the major automatic welding processes.

A further deterrent is that those manufacturers and specification agencies who have not kept abreast of the trends toward supplanting manual welding continue to write procedures and specifications on the basis applicable to manual welding.

The potential for automatic welding in this country is unlimited, as there is a preponderance of repetitive (i.e., similar, not generally identical) manufactured products, many of which call for automatic welding.

STATISTICS

Figure 1 shows a comparison of trends in a few typical branches of the welding industry.[1, 2, 20] The year 1943 was selected as a common denominator and a comparison of the percentage increase was plotted. Inert arc welding, the most recent of the automatic welding processes, represents the fastest growth. The volume of manual welding can be reflected by the sales of arc-welding electrodes and, as this chart shows, we find a slight downward trend while the over-all manufacture

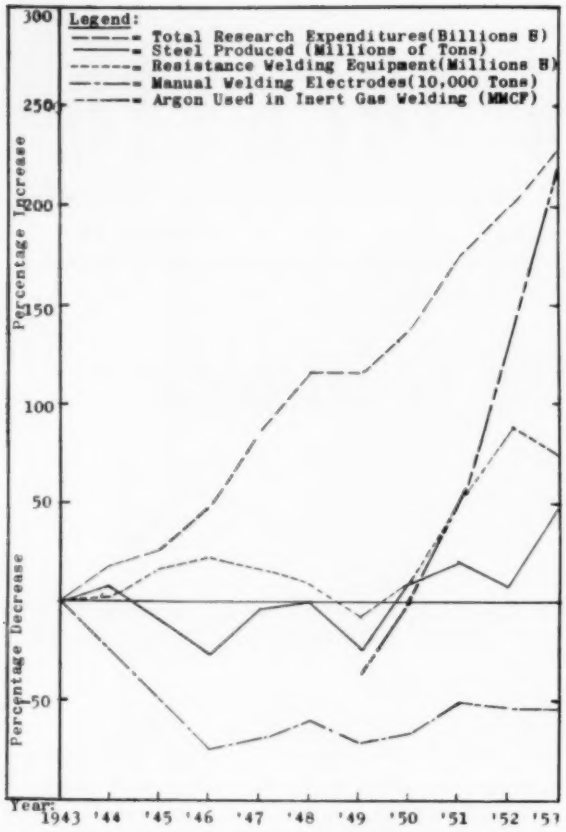

Fig. 1 Comparison chart of recent developments in the welding and steel industries, and total research

of steel is on the upgrade.[3] This is not an unhealthy sign in the evolution of welding if we consider that automatic welding is replacing manual welding where possible, and that prior to 1943 manual welding increased at a much faster rate than the over-all steel production. It is noteworthy that the total research in the United States, i.e., private industry, government, and educational institutions[4, 5] has more than tripled; the latest available figure for 1953 is four billion dollars.

This curve, as well as the resistance welding equipment curve, may have to be adjusted downward due to inflationary trends. However, the 1953 drop in equipment sales shows the necessity for an increased effort toward research. The amount of resistance welding research is steadily increasing, and the prediction is made that it will continue to increase at an even greater rate, and along with this increase in research, we will find the equipment sales rising.

Obviously, the volume of welding development work cannot be assessed by any statistical means because a great amount of vital research is carried out by companies which have no formal research programs. One of the purposes of this paper, therefore, is to review the various welding processes with respect to the more critical of the variables involved, and to stimulate interest in their eventual automatic control through research.

In reviewing welding processes with respect to degree of mechanization or automation, we should not overlook the basic process in which only a few variables are subject to control.

In *Manual Arc Welding*, the trend toward closer control of the variables is apparent by an increased utilization of fixtures as well as the development of the deep penetrating and contact electrodes. The latter type somewhat controls are length and the ambient hydrogen. Manual welding will always retain its place in industry on short production runs, special positions, physical limitations and field work. Further, semiautomatic devices are available where factors such as wire feed and position of the electrode are mechanically controlled.

Automatic *Oxy-acetylene Welding* was used extensively during the third decade in the oil and gas industry, and some gas pipe-welding machines are still in operation. However, this process is not readily adaptable to fully automatic operation as it was found difficult to consistently control variables such as gas mixture, distortion and fit-up. Gas welding has certain merits in automatic hard facing where the latter variable is absent.

A relatively recent development in oxy-acetylene welding is solid phase or *hot pressure welding* where the entire joint is heated simultaneously by means of oxy-acetylene flame impingement to a temperature below the melting point whereupon upsetting pressure is applied.

The process can be made automatic by means of controlling the following variables:

(*a*) Surface condition of the butting edges.
(*b*) Amount of upset.
(*c*) Upset pressure.
(*d*) Timing.
(*e*) The temperature of coalescence.

The latter is dependent upon oxygen and acetylene flow. Consistent control over the temperature of coalescence is difficult to maintain, as well as the surface condition of the material which requires the complete exclusion of air and impurities from the butting edges. One of the merits of this process is the relatively low initial investment in equipment. It is suitable for non precision work such as railroad track butt joints.

An important requirement to render a "hot" welding process automatic, expecially in hardenable materials,

Electrode type	H_2 by Volume in Arc Atmosphere, %	H_2 content of weld metal, wt. %
E6010	41.2	0.0014
E6012	35.6	0.0012
E6020	41.4	0.0009
E6015	8.7	0.0003
Bare wire (air)	...	0.0002
Inert-gas-shielded metal arc	...	0.0001

Fig. 2 Hydrogen concentration in manual welding compared with inert arc welding

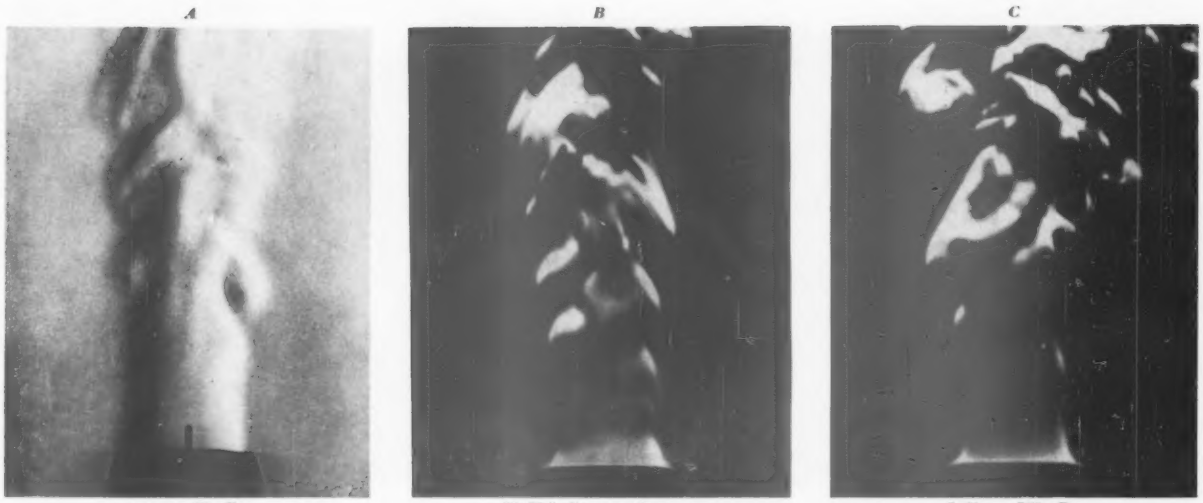

Fig. 3 Schlieren studies of gas coverage in various inert arc atmospheres

is the control of the heating and cooling cycle. By eliminating this variable, the *Cold Pressure Welding* process has found application for some hardenable materials such as aluminum alloys. However, the factor of maintaining uniform surface conditions in cold welding will render this process even more difficult to control in production for a given section than hot pressure welding.

The *Atomic Hydrogen Welding* process has been successfully adapted to automatic operation for high-carbon and alloy steels. In this process the welding temperature depends upon two means of transmitting heat to the work. One is the combination of hydrogen atoms to molecules, and the other is the combination of these molecules with oxygen. These reactions take place on the surface of the work; hence the guiding of the flame becomes very critical. In an automatic process this can easily lead to erratic results. Another unreliable phase in this process is the reaction between the atomic hydrogen and the base material which might introduce changes in the properties of the weld metal.

Inert Arc Welding. The difficulties encountered in atomic hydrogen welding have, during the past few years, been the subject of extensive research which resulted in the development of a welding process employing an inert gas as a shielding medium such as helium or argon which do not react with the base metal. Inert arc welding can be brought more readily under control than either oxy-acetylene or atomic hydrogen welding. The advantages, such as a quiet arc, the elimination of fluxes and post cleaning, should promote its development to one of the foremost automatic processes. It is gradually replacing gas and atomic hydrogen welding. This process is adaptable to so-called hard-to-weld metals. However, its application to some carbon steels is limited, in so far as the lack of fluxing action might produce porosity. The determination of proper balance of base and filler metal compositions and gas mixture for economical application on heavier stock, is already underway. Small additions of oxygen and carbon dioxide are yielding good results. However, the effect of the latter mixture is still to be evaluated.

The ideal condition of low-hydrogen welding toward which electrode manufacturers have directed their efforts in manual welding of steels of lower weldability is attained in inert arc welding, as illustrated in Fig. 2. Thus welds of consistently good mechanical properties are obtainable provided a complete coverage of the arc and weld puddle is maintained. Since the degree of shielding, contrary to submerged arc and manual welding, is invisible to the operator, testing means should be developed to make the coverage visible as shown in Fig. 3, by devices such as the Schlierenscope, at present a laboratory instrument. Thus complete protection from the atmosphere with the lowest gas consumption can be obtained. A good gas shield in inert arc welding allows a greater latitude in the carbon content of steel than possible in welding methods with a lesser degree of atmospheric control.

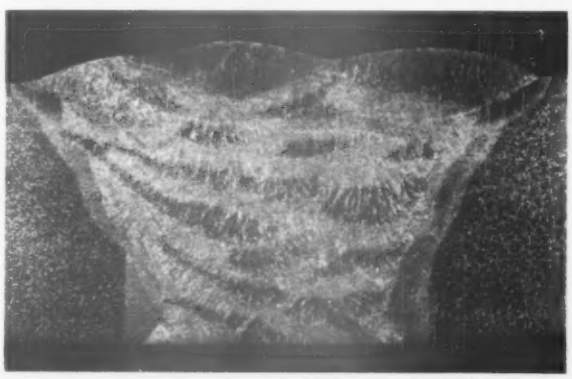

Fig. 4 Weld macrostructure obtained using argon plus 1% oxygen and reverse polarity current at 300 amp.; deep etched with ferric chloride. Magnification × 2

With further metallurgical development inert arc welding can be adapted to deep-groove welding on carbon steel. The groove would provide a retainer for the gas, thus rendering the process more economical and eliminating costly interpass cleaning, a manual operation hard to control. Investigations on the use of larger diameter wire than presently possible for deep groove welding should result in reduction of the number of passes. A macrophotograph of a multipass inert weld of carbon steel is shown in Fig. 4.

Sensitive factors in the inert-arc welding process are fit-up, preweld cleaning due to the lack of fluxing action, and the restriction of air movement. While in automatic welding there is a trend toward conversion from shop to field work, this is not expected to take place on a large scale in inert arc welding. Accurate fit-up can be obtained by means of well-designed clamping or tacking fixtures. This process has been used extensively in stainless steel, aluminum and other tube mills.

The nonconsumable process using tungsten electrodes does not necessarily require an automatic voltage control, provided the spacing can be maintained between the tungsten electrode and the piece by means of fixtures. In case of imperfectly aligned joints, it is necessary to use a fully automatic head where the vertical motion of the tungsten electrode holder is controlled electronically by the arc voltage.

Another method, employing a constant wire feed of a consumable electrode, is used for semiautomatic operation. The fully automatic filler wire method also uses a coil of bare wire. The rate of feed here is electronically controlled by the arc voltage.

The criteria of "automatic welding," the precise control of operating variables, is becoming apparent in inert arc welding. Development is now directed toward the elimination of a critical variable, the arc voltage, generally accepted as the controlling factor for many years. This is done by means of constant potential power sources which prove to have considerable advantages over drooping-type power sources. Thus electronic controls requiring excessive attention are eliminated. Moreover, the requirement of close arc voltage control when welding many nonferrous metals is obtained through the use of the constant potential power source. Another difficulty yet to be overcome is the requirement of very close arc length control for arc maintenance. The next step will be the use of a constant arc voltage power source.

The visibility of the arc in inert arc welding, in contrast to the hidden arc in submerged arc welding, is an asset in developing automatic control by facilitating studies of arc phenomena. These can be carried out in various shielding atmospheres and on different materials by high-speed pictures and oscillographs. Further advancements should lead to economies in automatic arc welding by a combination of inert gas and flux shields.

Early Stages of Automatic Arc Welding. Coated electrodes have played an important role in the adaptation of manual to automatic arc welding. The fundamental problem to be solved was the elimination of variations in resistance caused by burn-off. A patent race ensued during the thirties with one object in view; i.e., to maintain a uniform current supply at a constant distance from the arc by means of coil electrodes. Special shapes of electrodes, methods of piercing the coating, application of the coating just before welding, and, finally, providing a flux blanket during welding were the stepping stones in this development.[6]

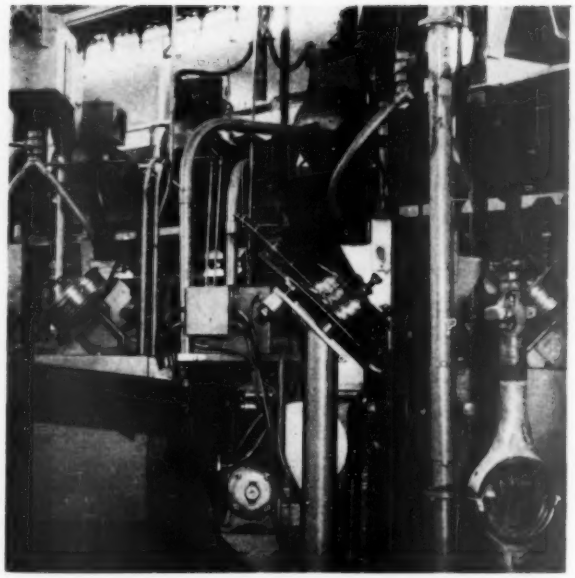

Fig. 5 Production line for automatic submerged arc welding automobile axle housings

Submerged Arc Welding. This process has found a wide acceptance because the blanket provides for easy metallurgical control due to adequate fluxing action and the complete exclusion of the ambient atmosphere, a variable hard to control in other flux-base arc and gas welding processes.

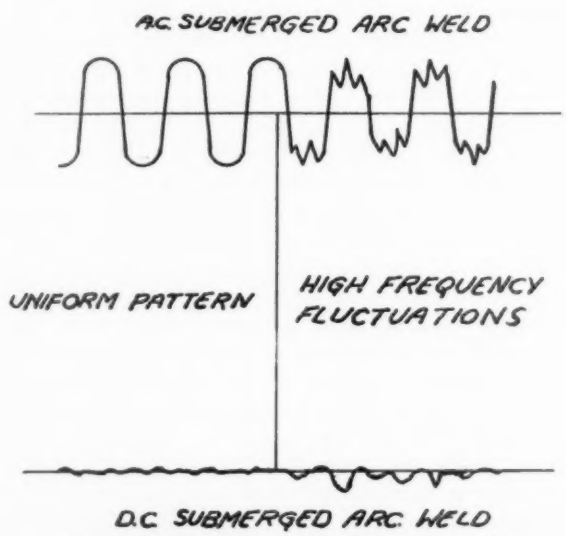

Fig. 6 Voltage patterns of submerged arc welds

Fig. 7 Submerged arc weld macrostructures showing the effect of variations in welding current. Magnification × 1.2

Submerged arc welding is often referred to as "Automatic Welding." This classification is somewhat presumptuous since the process does not become automatic by following a few simple operating instructions. There must be a rigid control over all prewelding, operating and postwelding conditions. This can be accomplished only by a thorough understanding and coordination of the essential variables which fall into the following categories:

1. Metallurgical.
2. Design.
3. Equipment.
4. Operation.
5. Testing.

1. Metallurgical control begins with the composition of the base and filler metals and is maintained through adequate fluxing action during welding. The complete exclusion of the ambient atmosphere provides ideal conditions of low hydrogen welding. Pre- and postheating are also metallurgical functions in submerged arc welding. Steels with low weldability ratings can thus be welded, and also mild steels will show a reduced tendency toward cracking. The assembly will be less sensitive to brittle fracture. The method of applying postheating before the weld has had a chance to cool is more economical than separate stress relieving or annealing treatments. Obviously, a postheat treatment which is done after the weld has cooled is ineffective against cracks caused by uncontrolled cooling. The results of present investigations on pre- and postheat control of manual welds can be utilized on automatic submerged arc welds for complete metallurgical control.

2. The product design must be adapted to the requirements of the automatic process with respect to

(*a*) Location of welds.
(*b*) Joint design details.
(*c*) Fixtures.

It is obvious that the welds should be located so that they are readily accessible for uninterrupted operation. It is not always recognized, however, that joint design details such as preparation and weld size, penetration and weld contour must be specified like other engineering and design data. Nominal sizes are inadequate and their tolerances, depending upon operating variables, should be specified. Bevel and fillet dimensions can be smaller than those for manual welds, due to the greater penetration obtainable in submerged arc welding. Finally, since during welding, the operator can neither see nor compensate for variations in design, as in manual welding, good fixtures are essential. For example the rod must be guided in the joint without attention from the operator. In the evolution of manual to automatic welding, we find that fixture design did not keep pace with the rapid progress. Fixtures designed for automatic arc welding are still often influenced by those used in manual welding.

An example of a complete departure from manual fixtures is shown in Fig. 5 of single-purpose fixtures incorporated in a high production line for automobile axle housings. This type of application is steadily increasing due to the ability to accurately control the welding operation. We should not be led to believe, however, that all automatic welding is mass production. On the contrary, the majority of automatic applications call for versatile fixtures which are readily adaptable to a variety of similar products.

3. Submerged arc welding equipment is designed for automatic adjustment of the arc length by maintaining constant arc voltage. For this it is imperative that the equipment have a consistent power source, and the maximum voltage drop across electrical contacts be minimized. Since arc instability is still a major problem in submerged arc welding, the constant potential type power supply source, as in the case of inert arc welding, should yield good results for arc stability and consistency.

Since in submerged arc welding the arc is invisible, a constant check on the arc performance must be kept. One of the most promising checking devices is a voltage recorder connected across the secondary terminals.

4. When the submerged arc welding operation is properly controlled, it will produce a conductive melt puddle in definite relation to the liquid weld metal. It will provide a steady curve of a type illustrated at

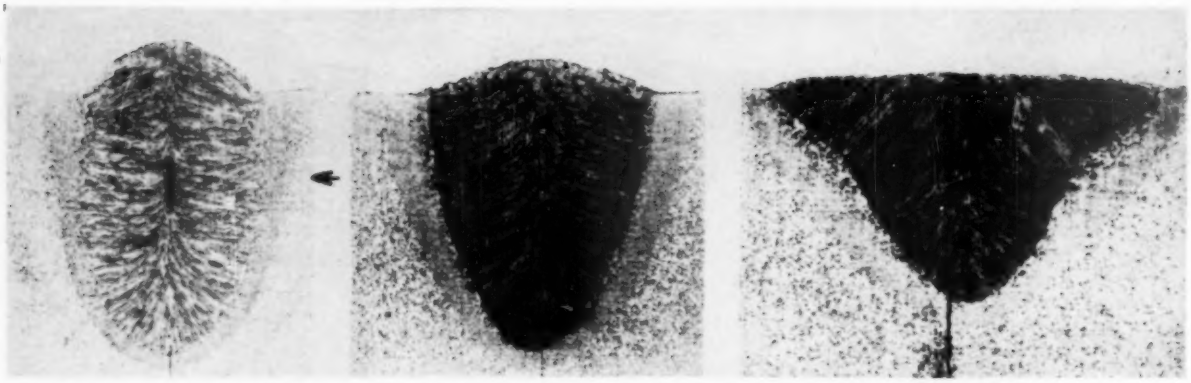

Fig. 8 Submerged arc weld macrostructures showing the effect of variations in welding voltage. Magnification × 1.1

the left in Fig. 6, free from high frequency fluctuations in contrast to the open arc methods.[7, 8] High frequency fluctuations superimposed on a straight line in case of dc, and or, a sinusoidal curve when ac is used, can often be directly traced back to deviations from the regular operation. (See right hand side of Fig. 6.) One frequent cause of this phenomenon, lack of penetration, can thus be detected if the other variables are well under control.

It would be simple if we could predetermine the amount of welding penetration in relation to the welding variables. Research on the subject has been summarized[9] by defining penetration as follows:

$$P = K\sqrt[3]{I^4/SE^2}$$

K = a constant (determined by the flux grade and composition).
I = welding current.
S = welding speed.
E = welding voltage.

Before this empirical formula can be utilized, more data on crater formation are needed.

A simple reliable means of testing penetration is by sectioning simulative test bars which have been welded by various setups, i.e., by methodically adjusting one variable while holding the others constant. In Fig. 7, three sections are made to show the effect of welding current variations while holding the other variables constant. Figure 8 shows the effect of variations in arc voltage, while other operating data are maintained constant, such as plate thickness $1^1/_2$ in., included angle of preparation 45 deg and welding speed $12^1/_2$ ipm.[21] This method of testing is extremely slow and costly and is of little use, unless we have some assurance of maintaining these ideal conditions in production. For this we must go one step further and correlate the findings of destructive with nondestructive tests, the simplest of which is visual inspection.

Although visual inspection of the surface is important, its application is limited to obvious surface defects. It cannot detect internal porosity and subsurface cracks. The left section of Fig. 8, for example, shows a deep rooted crack caused by welding at too low a voltage. One of the most promising means of nondestructively detecting this type of defect is the ultrasonic reflectoscope[10] where a crystal would transmit a sound beam into the material at the point of the arrow. Figure 9, upper diagram, shows the reflectoscope pattern when testing through an acceptable submerged arc weld and the lower reflectogram shows an indication caused by the reflecting interfaces of a cracked submerged arc weld. This method is particularly adaptable to discover root cracks in multipass joints inacces-

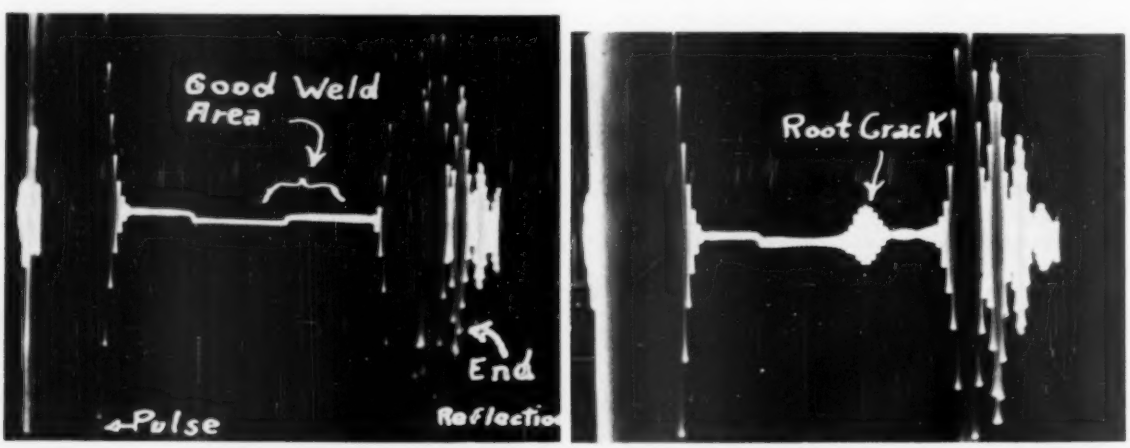

Fig. 9 Reflectograms of a deep groove submerged arc weld when testing a good weld (right diagram) and locating a root crack (left diagram)

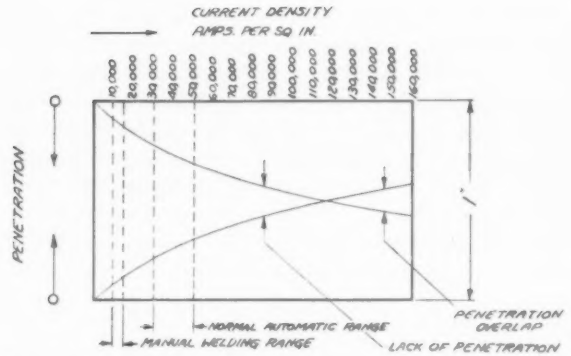

Fig. 10 Penetration through a two-pass submerged arc weld on a square butt joint in 1-in. plate versus current density

sible to X-rays, especially on carbon steels, while on some steels the signal may be lost at the heat-affected zone. The smooth surface obtainable by automatic welding assists in the application of the shear beam.

Full penetration welds are frequently obtained in submerged arc welding by means of one pass from each side. To insure the success of this method of obtaining full penetration, there must be reliable means available to detect lack of penetration. In addition to gouging and test milling, X-ray spot checks where applicable will help to discover lack of penetration[11] as well as porosity and slag inclusions. However, the application of X-ray as a quality control means is limited by the time delay to develop the picture. When refinements are more advanced on Xeroradiography,[12, 13] this method will enable a faster detection of the defect, limited only by the temperature of the weld. "Hot radiography," combined with Xeroradiography should become a promising quality control tool for automatic arc welding.

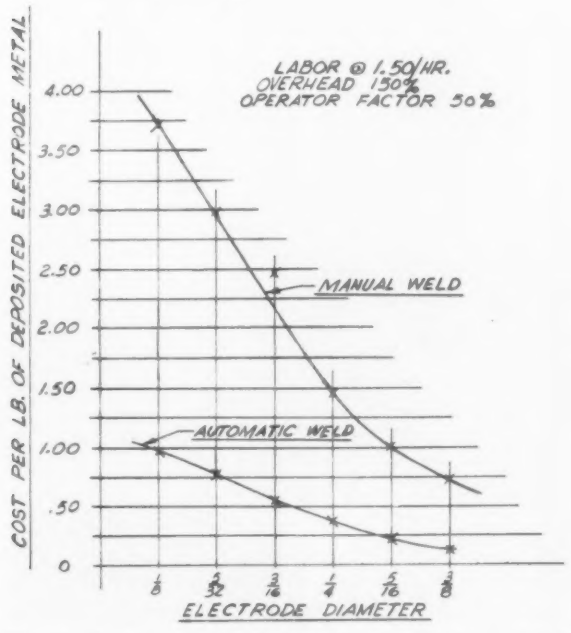

Fig. 11 Cost per pound of electrodes deposited versus rod size

At present, the nondestructive test most widely used is the magnetic particle inspection method which will also discover subsurface cracks; these are generally of greater magnitude than in manual welding and can thus be detected more readily. However, this inspection method is not reliable for defects such as small internal root cracks, blow holes, and underbead cracks.

In order to further increase the rate of deposition in submerged arc welding, the use of multiple electrodes, i.e., tandem and transverse electrodes, is being explored. While the use of multiple electrodes will increase the versatility of control over factors such as magnetic arc blow and fit-up, it will also result in additional control problems.

The use of high current densities is also being studied in an effort to reduce the amount of filler material. Figure 10 shows that it is possible to obtain full penetration on a square butt joint in 1-in. plate. This figure also shows the general range of current density where manual welding takes place and where automatic welding is generally conducted. This method along with ingenious fixture design is making it possible to weld in positions other than downhand.

We should not conclude the subject of submerged arc welding without a brief reference to the economy of the process which is due to the large size passes (see Fig. 7) which can be deposited at high welding speed. Figure 11 shows the considerable savings effected over manual welding.[14] Type AWS 6010 electrodes were used in this cost analysis which comprises material, labor (including chipping) and overhead. The manual process is favored because of the 50—80% higher operator factor that can be obtained with submerged arc welding by the use of fixtures. A portion of this margin is absorbed by developing welding and testing procedures and coordinating these with joint design to obtain maximum benefits. On the other hand, when automatic arc welding is processed as any other routine manufacturing operation without regard to its design and control requirements, it may prove to be even more costly than manual welding.

RESISTANCE WELDING

Resistance welding, comprising several pressure welding methods, embodies the requisites for automation in welding because there are no metallurgical control problems caused by heterogeneous filler metals.

Spot Welding is often referred to as "resistance welding" since it is the most widely used resistance welding method. Procedure control methods long in use have perfected this process with respect to proper values of current, time and pressure, where current timing is most critical.

Factors still often disregarded are precleaning of the material, the geometry and temperature of the electrodes, spot spacing and proper placement of the work with respect to the machine.

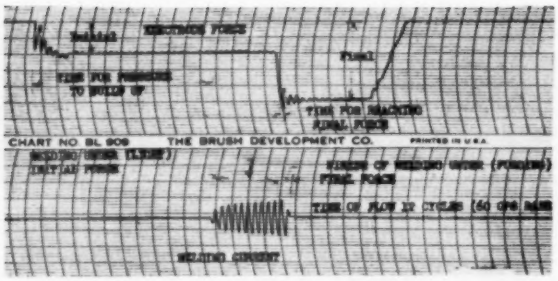

Fig. 12 Spot welding oscillogram indicating a double pressure cycle, duration of pressure application and current flow

The advances made in spot welding are due to three factors. These are: the completion of extensive research programs, control of variables by instrumentation (as for example, the oscillogram shown in Fig. 12 which recorded the amount of welding current, electrode force and current timing), and effective application of statistical quality control methods.[15]

Some of the experience gained with spot welding can be applied to other resistance welding processes. Projection welding lends itself more readily to consistent production since the geometry of the electrode has little effect on the process, and current timing and surface conditions are not so critical as in the standard spot welding process. However, electrode force and prewelding variables such as design of the projection, relationship of the various projections and edge spacing are more critical. Effort is now directed toward converting recording systems to control devices for the purpose of obtaining consistent output independent of power and pressure fluctuations.[26]

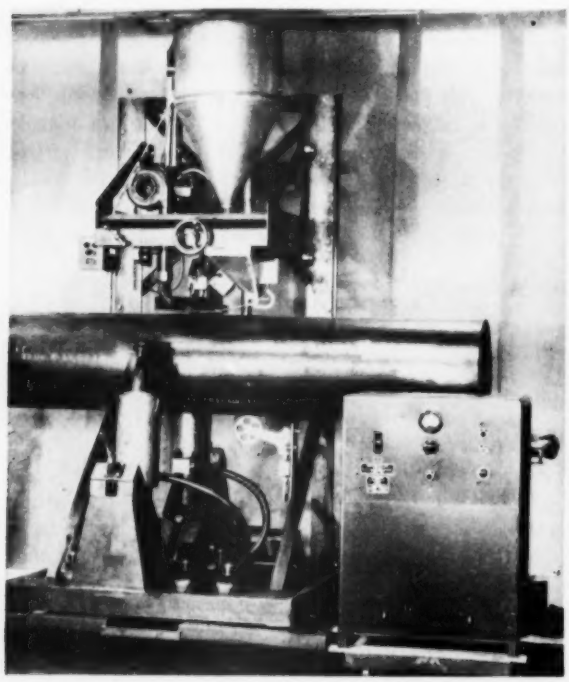

Fig. 13 Magnetic scanning of seam-welded pipe (22-in. OD 5/16-in. wall) showing side view of inspection unit with hopper and yoke

Seam Welding has been fully automatic in pipe mills for a long time, accomplished through vigilance to solve the ever present problem of operating variables. Figure 13 shows a pipe after it has emerged from the welder and is inspected immediately by the magnetic particle method on a white surface as in Fig. 14. This inspection is now performed by fully automatic scanning. It is operated by an optical system which throws an image of the passing weld onto the target of a photoelectric cell in about the same manner as a television image is broken down and reconstructed.[16] This is a perfect setup where research has resulted in a fully automatic welding cycle and where quality inspection plays an integral part. Deviations in the output of the system resulting in cracks in the seam weld are instantly fed back to control the input of the welder.

Flash Butt Welding originated from the primitive blacksmith art. Nevertheless, this technique is adaptable to a greater degree of precision control than any other welding process. The flashing action consists of a series of recurring short circuit currents, appearing erratic. This apparent irregularity, however, is very misleading. Actually, flashing produces an extremely uniform heating of the interfaces which can be controlled to obtain a given temperature. As in the case

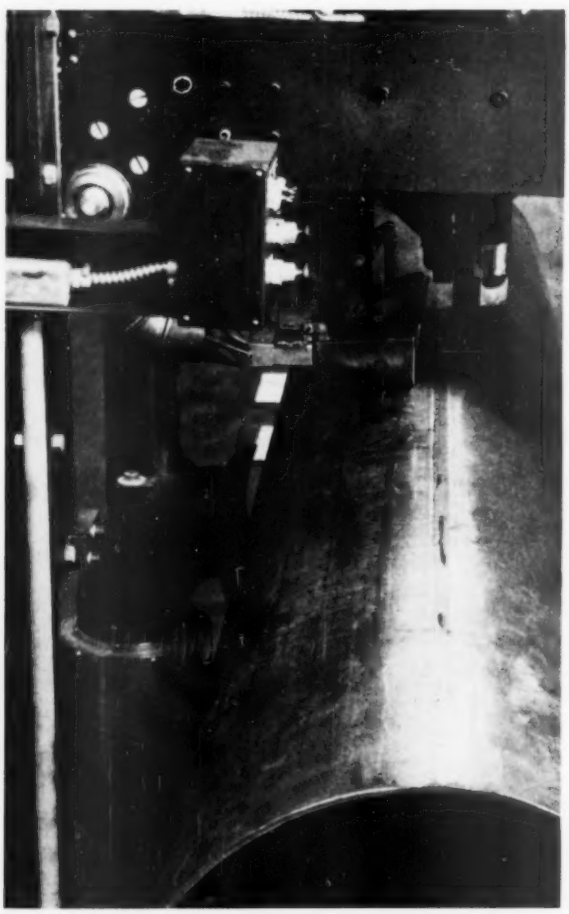

Fig. 14 End view of magnetic scanning equipment showing indications of defects on seam-welded pipe

of spot welding, no additional filler material is used, but contrary to spot welding, a uniform cross-sectional area is maintained resulting in a structure which is metallurgically and mechanically more homogeneous than any other type of weld. The parts can be joined within close dimensional tolerances as distortion problems do not arise.

By proper adjustment the process is suitable for welding many alloys which cannot be welded by fusion. Cracked and unfused root passes which give rise to many difficulties encountered in fusion welding are absent in flash welding. Deep seated internal defects can be brought under control by a close check on the upsetting action to insure that it initiates at the center, whereupon it propagates uniformly to the perimeter of the section. Crater porosity can be eliminated by operating with a minimum energy level during the flashing cycle so that the ratio of crater size to upset travel is well within the control of the upsetting action. Flash welding employs higher current per contact area and voltage unit than any other known process. Higher current densities and lower energy levels are helpful to weld alloys of low weldability rating, provided the variables are held within close limits.[17, 18]

Preheat is advisable to reduce the temperature gradient in flash welding hardenable steels. Preheating will further facilitate the initial flashing action and will maintain flashing at a lower energy level. With its use, however, the variable of preheat temperature is introduced.[27]

Preheating is often done by resistance heating of the butting interfaces as used for upset welding, a forerunner to flash welding. The upset welding process is still in use, but it often requires special surface preparation and is difficult to control, especially on heavy sections.

The fact that flash welding is adaptable to a greater degree of precision control than any other welding process does not imply that flash welding procedures can be carried out in cook-book fashion by means of a few specified machine settings. In flash welding, we have a great number of variables which can be brought under control only by careful screening and correlating with the property of the weld and its defects.

In order to determine the cause of a defect, the location must be known. Defects in flash welding can thus be grouped as follows:

1. Defects in faying plane.
2. Defects between faying plane and die area.
3. Defects in die area.

The types of defects should be further analyzed with respect to their specific causes, depending upon the product.

The object of procedure control is to confine the occurrence of any defects to the surface, which in cases of types 1 and 2, should be outside the sectional area and thus removed with the flash. When, in the course of a production run, spot checks by sensitive nondestructive testing means discover minute surface defects existing after trimming, it is an indication of operational inconsistencies. By discovering these defects at the onset, the cause can be remedied immediately and prevent mass rejects which may result from relying on visual inspection.

Since no general formula can be given to determine the best testing method for each application, this will be considered in the following section devoted to this important phase.

Nondestructive Testing of Flash Welds. The magnetic particle test can be applied to ferro-magnetic materials to locate invisible surface and some subsurface defects, while on paramagnetic materials fluid penetrants are applicable for surface inspection. Radiography should be used with discretion for testing flash welds, since a reliable degree of sensitivity depends upon directing the radiographic beam within the plane of the defect. Certain internal faying plane defects can be discovered with this method.

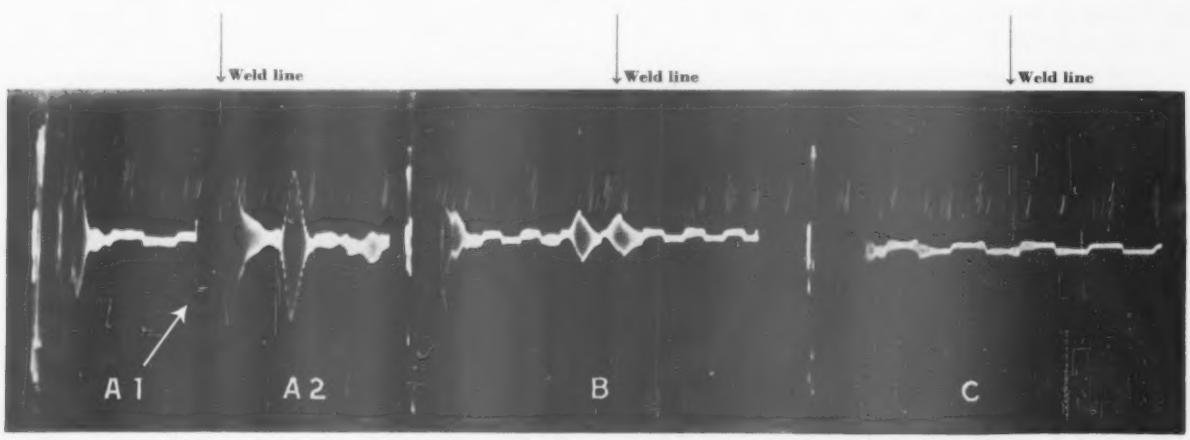

Fig. 15 Reflectograms of heavy section flash welds indicating typical defects (A and B) and an acceptable weld (C)

A1. **Ultrasonic reflectogram of a cracked weld at the weld line.** ***B.*** **Ultrasonic indications on either side of a flash weld caused by undesirable upset flow lines.** ***C.*** **Ultrasonic reflectogram of a good flash weld showing normal texture found in 5046 forged steel.**

Further nondestructive tests are the recording oscillograph to keep a constant check on the flash welding operation, and proof testing of the assembly soon after welding. Visual tests to discover gross defects still perform an important function for pre- and postwelding control. Future progress in flash welding is linked closely with development of suitable nondestructive testing facilities. The ultrasonic reflectoscope which is coming into wider usage is a good beginning. The indications of reflectograms of known or synthetic defects should be correlated with results of other types of tests, for quick differentiation between harmless and serious defects. Ultrasonics will also reveal defects in materials, such as laminations, which would make the material unsuitable for flash welding.

In the reflectogram, Fig. 15*A*, the indication A1 is one of high amplitude picked up from the interface of a crack in the weld line. Due to high sensitivity, a secondary indication caused by porosity in the outbent fiber region is shown at A2.

The reflectoscope has assisted in the development of flash welding heavy concentrated sections up to nearly 100 sq in. where numerous destructive tests are not practical. Recent development has resulted in using this testing device to discover occurrences of operational inconsistencies with a view to tracing and correcting the cause. For example, Fig. 15*B*, shows indications on either side of the weld due to small outbent fiber defects. Figure 15*C* shows a good flash weld in an alloy steel.

Ultrasonic testing seems unsuitable when applied to certain materials because the reflections and diffractions from distorted grains and the heat-affected area are difficult to distinguish from actual defects. Investigations are now under way toward establishing test standards by measuring the area of the reflecting interfaces.[19] This method should be applicable to flash welds since the orientation of defects is generally known.

It is believed that ultrasonics will find further use for flash welding, especially on heavy sections and carbon steels, but it should be applied with caution and its limitations should be determined by tests.

Destructive Testing of Flash Welds. The welding procedure should be set up, based on results of inexpensive facsimile test bars which are forced to fracture through the weld, thus affording a 100% inspection of the weld area. Destructive tests, such as free and reverse bend tests and notched-bar impact tests, will disclose internal defects which should be eliminated before the operation can be released for a pilot run or production. An inexpensive and yet conclusive test is the embrittlement test performed by chilling test bars in liquid air, whereupon they may be broken by impact to reveal faying plane defects. Correlating results of destructive tests with operational inconsistencies to which the various defects can be attributed, will determine a good flash welding procedure that will require only a minimum of destructive spot checks during production.

Tensile tests, the standard method of evaluating flash welds, have long been in successful use.[30] Their merits consist in supplying basic design data by determining the mechanical properties of the materials which have been subjected to various heating and cooling cycles from welding and heat treating. Moreover, test bars machined from the center of the weld may disclose deep rooted defects, thus revealing fundamentally faulty setups.

However, the limitations of tensile tests should be kept in mind. The area which can be tensile tested is limited by the capacity of the tensile machine. For example, a 0.505-tensile bar will test only 5% of the area of a flash weld in a 2- x 2-in. section. Furthermore, it is costly to obtain representative figures for the consistency of a setup, as a large number of welds and tensile bars are needed. The main limitation in the use of tensile tests is that the location of the fracture depends upon the condition of hot and cold working and the type and degree of heat treatment. When a fracture of a static tensile test occurs outside the weld and heat-affected zone, the results merely indicate the properties of the parent metal.

Too frequently, specification agencies rely solely upon tensile tests for the purpose of evaluating the quality of flash-welded joints. It is often necessary to investigate toughness and notch sensitivity. Indiscriminate use of tensile tests for flash welds may be the cause of erroneous conclusions sometimes made with respect to service requirements of flash welds.

Investigative destructive tests such as tensile, macro- and microetchings[30] should be correlated with the initial setup as well as nondestructive tests so that production units need not be destroyed unnecessarily.

Flash welding came into use at a later date than fusion welding, and many of the testing methods already in existence for fusion welding were directly applied to flash welding. While some of the methods are suitable, the very differences in the welding processes indicate that testing methods should be adjusted to the characteristics of the respective welding method.

Present *research in flash welding* has three main objectives:

(*a*) Establishing suitable testing methods.
(*b*) Control of upset conditions.
(*c*) Control of the heating and cooling cycle, especially with a view to obtaining a uniform temperature distribution prior to upset.

While little information has yet been made available on actual upset conditions, several studies have been conducted to determine the temperature prior to upset as shown briefly in the following résumé:

1. An empirical method of predicting the temperature distribution at the instant of upset by establishing a flashing parameter[22] for parabolic flashing conditions, expressed as $P = aS/A$.

2. Establishing the initial and final flashing tem-

perature by the following formula:[23]

$$T_0 = T_f - K\,(N/vQ)$$

3. General studies on contact resistance.[24]

4. Experimental work relating the final flashing temperature to process variables such as flashing distance and flashing speed, which were found to be the most critical variables.[25]

The following symbols were used in the foregoing survey:

P = flashing parameter.
a = platen acceleration.
S = section thickness.
A = Initial clamping distance.
T_0 = Initial flashing temperature.
T_f = final flashing temperature.
Q = cross section.
K = constant.
v = flashing velocity.
N = machine output.

The control of the interface temperature at the point of upset as well as the temperature gradient is necessary to gage actual upset pressure. The control of power output independent of supply line fluctuations is the first step toward the solution of this problem.

Electronic recorders, oscillographs, other electrical, hydraulic, and mechanical indicators play an important part in setting up automatic control of the flash welding operation for equipment calibration and obtaining accurate data of the welding variables. However the data obtained from all these devices provide no direct information toward the output, i.e., the quality of the weld. What is needed is fundamental research toward the development of testing methods to gage the output so that they can be directly applied or fed back to the input, analogous to the example cited in seam welding. It is believed that flash welding lends itself toward this type of fully automatic application.

The control of the upsetting motion is another item requiring further investigation in order to arrive at a specified pressure gradient. It is not always desirable to "upset as fast as possible."[18, 25]

Another outstanding problem is the effect of the power factor[23] of the welding transformer on the welding variables.

Since the flash-welding process is suitable for welding heavy sections, the trend in equipment is toward design of more rigid machines to reduce the amount of springback, a variable that tends to interfere with consistent operation.

FUNCTIONAL REQUIREMENTS

In the evolution of welding from a craft to a science, the organization of welding operations has also passed through several stages. In the early stage, welding procedures were left to the discretion of skilled shop personnel. Later, welding was treated on the same level as other manufacturing processes. This was a great improvement; however, where automatic welding was used extensively the high degree of specialization required proved that this system was often deficient in the ability to permit the expedient solution of specialized problems. Moreover, attention is now focused on the fundamental requirement of welding, i.e., design. This approach is necessary because an improperly designed weld with respect to service requirements will form the weakest link and reduce the utility of the finished product, not to mention the resultant production bottlenecks. On the other hand, a well-designed weld will greatly facilitate in manufacture. This trend in welding engineering is merely following the same pattern as did design engineering, which in the early stages of development was often considered an unnecessary overhead item.

It would be erroneous to conclude that large organizations, because of their extensive research facilities, have a monopoly on utilization of automatic welding. This is not the case. Small organizations may have access to equal or sometimes superior facilities, if they wisely contract their more complex problems to specialized research organizations. The size of the company is only a minor consideration. A small company generally has the advantage of flexibility required for the utilization of new developments with respect to welding and testing methods. On the other hand, the

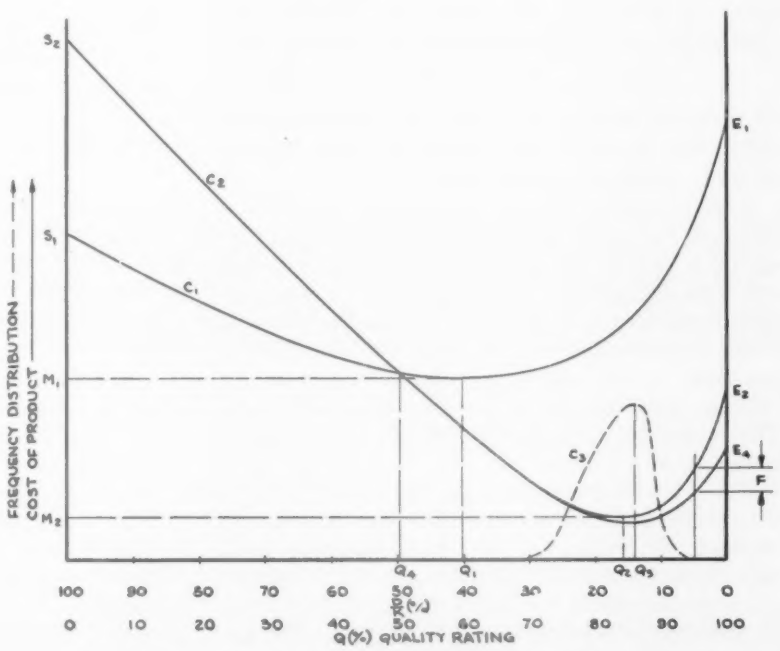

Fig. 16 Welding cost related to quality rating

larger company may have more working capital and larger production quantities of similar items. Actually, the results of surveys show that smaller companies spend a greater portion of their sales dollar on research, which also absorbs a greater percentage of their total employees than the larger firms.[4, 29]

The main functional requirements of an organization employing extensive use of automatic welding have been summarized:

1. Emphasis on joint design.
2. Close affiliation of the welding division with the quality control and research divisions.
3. Welding procedure control to function dissociated from scheduling and processing pressure.[31]
4. Flexibility to permit expedient solution of welding problems and the incorporation of new developments.
5. Welding functions should be vested in a minimum of specialized personnel, so that welding problems may be quickly and efficiently handled by persons directly concerned with the problem.[32]

COST FACTORS

In the welding industry there is much discussion on the following:

1. Does it cost more to make a good weld than a poor one?
2. Under what conditions can automatic welding be more economical than manual welding?

The answers to these questions, as complex as they first appear, are simplified by expressing quality as a function of the factors of variability, such as prewelding standards, machine operation, operating variables, human element and other unknown factors. This relationship can be formulated in the following way:

$$Q = \sum V_{1,\,2,\,3,} + H + X,$$

where the number of unknowns will determine how many such equations are needed for their solution, generally obtained from test data.

When expressing the cost of production in relation to the quality rating of the product, it is known that poor quality is very costly as it necessitates extensive repair and high scrap losses. Conversely, extremely high quality standards will be expensive, thus there must be a cost minimum between the two extremes. Various standards can be applied to express cost data, for example, as a function of the percentage of defects. Thus a curve is obtained as shown in Fig. 16 where C_1 is typical of a manual weld and C_2 of an automatic weld. While in manual welding lower quality (S_1) is not so costly as in automatic welding (S_2), the difference becomes less pronounced until the break-even point, Q_4 is reached. Beyond that point, the cost advantages of automatic welding are substantial up to the point of Q_2 whereupon the control cost will increase. The goal of the quality control division is to obtain a frequency distribution (C_3) with the maximum (Q_3) close or slightly above Q_2. This outline does not imply that a statistical quality control system is always applicable to automatic welding. In fact, a qualitative system, based on nondestructive testing is generally preferable as it points out the inherent weaknesses of automatic welding and thus assists in process improvement. By the time a weld is made, most of the cost of the product has already been incurred. Detailed information pertaining to the cost of research and quality control versus over-all savings effected would indicate where the need lies. The following symbols have been used in the preceding paragraph:

V_1, V_2, V_3 = factors of variability.
H = human control factors.
X = unknown factors.
C_1 = manual welding cost chart.
C_2 = automatic welding cost chart.
C_3 = frequency distribution chart.
F = cost of control.
M = point of lowest cost.
K = constant.
D = defects per lot.
Q = quality rating = $(100 - D)/K$.
Q_4 = break-even point.

One of the goals of automatic welding is the constant striving toward elimination of the unknown factors including those still under the operator's control. Operator qualification procedures are meaningless when applied to fully automatic welding as the operator is no longer controlling the process by his skill. Procedure qualifications only are applicable to a well-devised automatic welding operation. In automatic welding, the operator's skill need not be wasted, but can be converted to other channels, e.g., to aid in the maintenance and consistency of machine operation by understanding the control devices and becoming familiar with new control measures that are being introduced for the benefit of both operator and operation.

CONCLUSIONS

American industry owes its leading role, in spite of prevailing high labor rates, to the application of efficient production methods developed from systematic and coordinated research. This principle should be applied to automatic welding in three ways, i.e., equipment, product and process development, and testing.

Although fully automatic welding mass production lines are in existence, as for example in the automotive and tube mill industries, the majority of the welding industry has as yet insufficient application for continuous production. In order to provide adequate quantities to apply automatic welding, we find that parallel with the development toward automation in welding, there is a trend toward specialization. Some companies specialize in welding of landing gears, crankshafts, rings,[30] chains, pressure vessels and countless other objects.

Even with a variety of jobs, we find that planned research can be directed toward modification of diversified production of similar items to be accomplished by universal tooling. Deterrent to this way of thinking has been the initial investment in tooling necessary to carry out this program. If put into practice, it will provide sufficient production quantities to justify the application of automatic welding, and the expenditure of research to their specific line of products.

An integral part of automatic welding is the application of testing methods to obtain the desired quality.

Since destructive testing is an obstacle to economic production, the following approach is necessary:

1. Correlate destructive and nondestructive tests toward a greater application of the latter.

2. Apply nondestructive testing as quality control measures immediately following the welding operation.

3. Correlate welding variables with results of nondestructive tests.

All welding processes have one aspect in common, i.e., a variety of factors contribute toward a quality standard of the product. These factors are prewelding standards, machine operation, operating variables, postwelding operations, human element and other unknown factors. All of these factors are a summation or integration of all sources of variability known and unknown. Thus the necessity for organized research becomes apparent especially regarding the regulation of the unknown factors.

We should not overlook the value of welding research done on the job, since many welding problems can best be solved in this way. Therefore, for many firms it is not essential that they have a modern research laboratory, the more intricate problems can be contracted with research organizations and specializing in such services. The Welding Research Council acts as coordinator for the various research programs; therefore, large and small companies alike should be affiliated with the Welding Research Council.

In joining metals by welding, we find a great diversification of problems as they deal with mechanical and metallurgical, as well as electrical, variables. These should be coordinated by research to give us "controlled" or "automatic" operation.

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Flash Welding Aluminum to Copper Tubing

Welding procedures for production flash welding of copper to aluminum tubing to meet stringent requirements

by W. F. Haessly

Synopsis

This paper concerns the practicability of using flash welding for joining copper to aluminum tubing on a production basis where weld quality must fulfill the most stringent requirements. It is only in recent years that the welding technique has been recognized for mass production because of the ability to control consistency.

Basic welding procedure is outlined and weld schedules are given for two common material sizes where pinch-off dies were used to strip off the external upset metal. Successful welding equipment is discussed with emphasis on those factors which are credited mostly for controlling consistency.

Photomacrographs are included to illustrate the usage of metallographic examination for selecting optimum machine settings as well as destructive and proof test procedure suitable for production control.

INTRODUCTION

THE most common application for this type of joint is in the refrigeration industry where it is often desirable to terminate aluminum tubing with a short length of copper tubing. Termination of the aluminum tubing in this fashion is for ease of making solder joints at assembly, particularly if it should be required to make field changes.

It is necessary that the joint must withstand mechanical abuse when imposed directly on the weld and still be pressure tight to refrigerant gases. These requirements must be fulfilled when the weld area is reduced to that of the parent material.

An accepted and proved phenomenon is that a brittle alloy is formed when these two metals are united by flash butt welding, and variations in this brittle zone contribute to weld inconsistency. Control of the brittle zone is obtained through application of the proper welding technique with equipment that has been developed to apply the technique.

MATERIAL SPECIFICATIONS AND TUBING SIZES

Specifications for the aluminum used were that it be 3SO and within commercial tolerance limits.

Specifications for the copper were that it be plug-drawn with a minimum purity of 99.9% and with a maximum of 0.003 to 0.004% phosphorus.

Both materials were used in the annealed state and free of excessive corrosion and oxidation.

The aluminum is generally cut off at a 2-deg angle as shown in Fig. 1, to make it easier to start flashing. The copper is cut square and burrs are kept to a minimum, particularly that which is forced inwardly during the cut-off operation. Burrs on the aluminum end are not critical but still the cut should be kept reasonably clean.

The most common tubing sizes in present-day usage that call for welded joints are $^{7}/_{16}$ OD by 0.050 wall and $^{5}/_{16}$ OD by 0.050 wall. It is for this reason that extensive welding analysis has been concentrated on these two sizes.

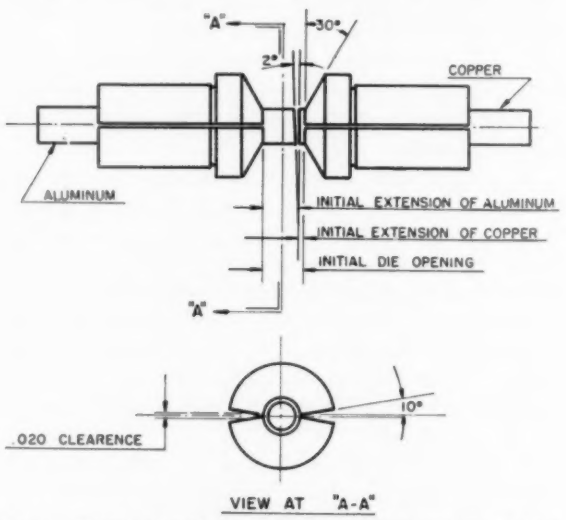

Fig. 1 Sketch showing work with respect to a typical set of pinch-off dies

FACTORS THAT AFFECT WELD CONSISTENCY

When copper and aluminum are fused together at welding temperatures, an extremely brittle alloy is formed that serves as the cementation between the two base metals. It is necessary that the thickness of

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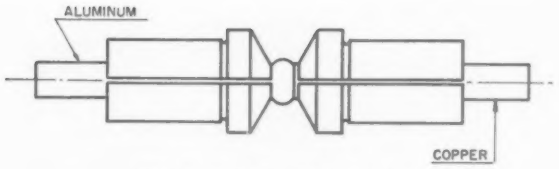

Fig. 2 Cold upset formation

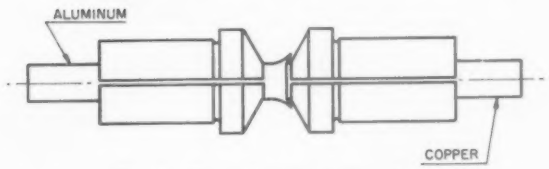

Fig. 3 Correct upset formation

this formation be kept at a minimum in order to produce a joint which can be flexed to the limit that the base metals will withstand. This requirement is also essential if the joint is to possess good impact characteristics.

Copper and aluminum have extremely narrow plastic ranges which means that slight variations in the degree of heating will readily cause considerable variations in the extent of plasticity. Any variations in plasticity will readily affect the forging force applied to the weld when upset pressure is applied at a predetermined amount for a fixed distance. This in turn causes variations in thickness of the alloy formation which contributes to joint inconsistency when judged accordingly by ductility and impact characteristics.

Practically the entire upset formation of a copper to aluminum flash weld is made up of aluminum; or, in other words, copper is wiped by the aluminum when upsetting starts and progresses from the weld interface as shown in Fig. 3. Upset formation in this manner has been found to be of importance to keep the thickness of the alloy formation at a minimum. It is therefore necessary that the proper temperature gradient be established prior to upsetting if upset formation is to progress in this manner.

WELDING TECHNIQUE

The oscillogram for a joint made in $^{7}/_{16}$ OD aluminum on an air upset machine is shown in Fig. 4. The top trace is platen travel with respect to time, and the bottom trace is the corresponding welding current as measured in the transformer primary. The current trace includes load resistor current and the amplitude is indicated on the chart before flashing starts.

The oscillogram shows that flashing was started without any tendency for the ends to freeze together. Freezing at the start of flashing makes it difficult to establish the proper temperature gradient in the aluminum for upsetting. This generally causes upsetting to take place in the aluminum behind the weld interface, and it affects the quality of the joint. This type of cold upset formation is shown by the sketch in Fig. 2.

Flashing times ranging from 12 to 90 cycles were in-

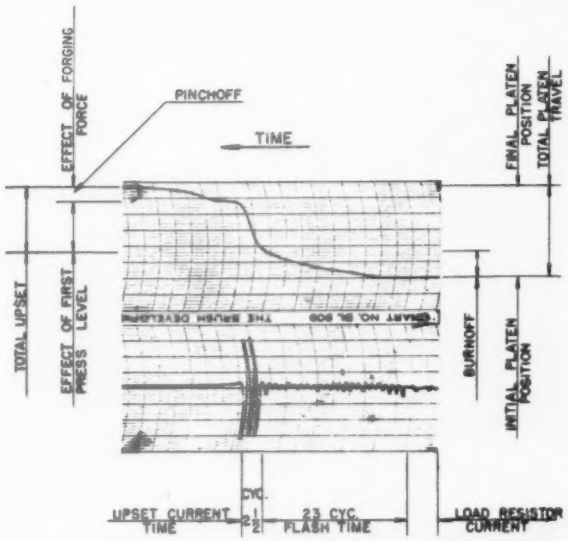

Fig. 4 Oscillogram for a joint made in $^{7}/_{16}$ OD by 0.050 tubing showing platen travel with the corresponding weld current amplitude

vestigated and it was found that variations in this time had no effect on either weld consistency or quality of the joint. The longer flashing times merely required that additional material be extended from the dies to be flashed off. The minimum time was found to be that which would establish a steady flash and increase its intensity to the extent that the required temperature gradient was established in the work ends for upsetting.

Platen velocity at the start of flash was 17 ipm and 35 ipm at the end. Acceleration during the flashing time was at an exponential rate which had been determined as optimum for this material combination.

The platen travel recording in Fig. 4 shows that the upset force was applied in two distinct pressure levels. Upsetting in this manner has been found to be of importance as a means to enable the welding machine to compensate for slight variations in the degree of plasticity since the work stops the forward motion of the platen due to the first pressure level. This is true only when upset force is applied by air or by hydraulic pressure, which makes it possible for the same pressure to be applied to the work regardless of any variation in an opposing force that may exist.

The required upset force to initiate the first pressure level is not entirely dependent on the size of tubing involved, but it must be that which will cause a definite change in platen velocity at the desired instant so that flashing stops and upsetting starts. It is therefore dependent on platen velocity at the end of flash, the mass of the platen, and the voltage used for flashing. Pressures that are too low will make the upset point not definite and consequently the number of cycles of upset current flow will vary from weld to weld which will cause corresponding variations in the degree of plasticity. The required upset force must also be that which will follow through with a platen velocity suitable for

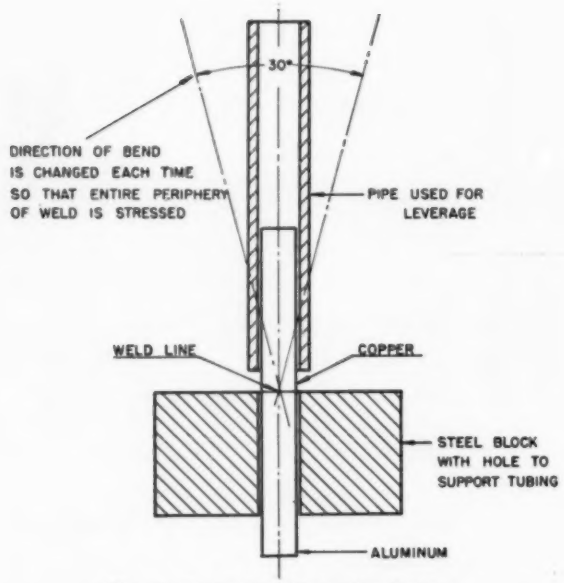

Fig. 5 Setup for destructive testing

upsetting after a definite upset point has been established. Platen velocity during the first upset pressure for both of the referred tubing sizes was 235 ipm.

It can therefore be summarized that fulfillment of three factors is necessary to obtain control of the brittle zone. These factors are:

1. Establishment of the proper temperature gradient so that upset formation will progress in the above described manner.

2. Control of the degree of plasticity by keeping the established temperature gradient consistently the same.

3. Compensate for any *slight* variations in plasticity which may exist by permitting the work to stop the forward motion of the platen at the end of the first upset pressure level.

The second upset pressure level or forging force is used to produce an aluminum structure immediately behind the weld interface that is homogenous and free of cracks. It is also used to close the dies to a definite position as controlled by a positive mechanical stop and thus complete the action of the pinch-off dies on the external upset metal.

Weld Schedule

Tubing sizes	$^5/_{16}$ *OD x 0.050*	$^7/_{16}$ *OD x 0.050*
Extension copper, in.	0.062	0.062
Extension aluminum, in.	0.250	0.359
Initial die opening, in.*	0.375	0.484
Final die opening, in.	0.016	0.016
Flash time, cycles	30	30
Upset current time, cycles	$1^1/_2$	$2^1/_2$
Upset force (1st pressure level), lb	1,300	1,300
Upset force (2nd pressure level), lb	2,000	2,250
Upset current, amp	19,500	28,000
Flash-off, in.	0.093	0.093
1st pressure upset, in.	0.172	0.267
2nd pressure upset, in.	0.046	0.062
Total upset, in.	0.218	0.329

* Initial die opening includes thickness of spacer or gaging bar which was $^1/_{16}$ in. thick. It is equal to extension of the copper plus extension of aluminum plus thickness of spacer bar.

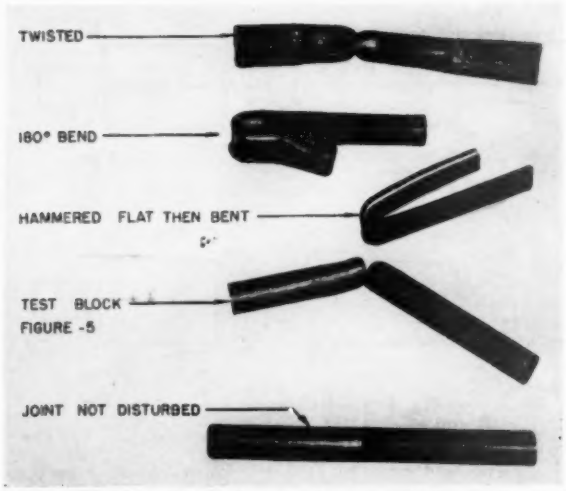

Fig. 6 Welds subjected to various methods of physical testing

DESTRUCTIVE TESTING AS A GUIDE FOR SELECTING OPTIMUM MACHINE SETTINGS

One method of destructive testing that has proved satisfactory is shown in Fig. 5. The aluminum portion of the weld to be tested is inserted through a hole in a steel block to the extent that the weld line is at the block surface. The copper extension is flexed back and forth approximately 20 deg with respect to the original axis. A piece of pipe is slipped over the copper end to within $^1/_2$ in. of the weld line to keep the copper straight and direct the bending so that it must occur in the vicinity of the weld. Each successive bend is established in a new plane to determine if any portion of the weld is of inferior quality.

A second method is to hammer the joint flat and then to direct bending at the joint until fracture occurs. Failure should be in the aluminum for either method and leave the copper coated with aluminum. The exposed surfaces at the break should show evidence of a continuous granular structure.

Both of these test procedures can be conducted with or without the internal upset metal removed. However, it is felt that the test is more severe if it is first removed.

Impact studies on the joint have been made by supporting the copper to within $^1/_4$ in. of the weld line, and then striking the aluminum approximately 1 in. from the weld with a swinging weight. The object is to use a sufficiently large weight and to swing it through an arc great enough to cause fracture of the joint. Measurement of the distance that the weight travels after fracturing the joint was used as a comparative measure to determine consistency of the brittle zone.

METALLOGRAPHIC EXAMINATION AS A GUIDE FOR SELECTING OPTIMUM MACHINE SETTINGS

The photomacro and photomicrographs shown in

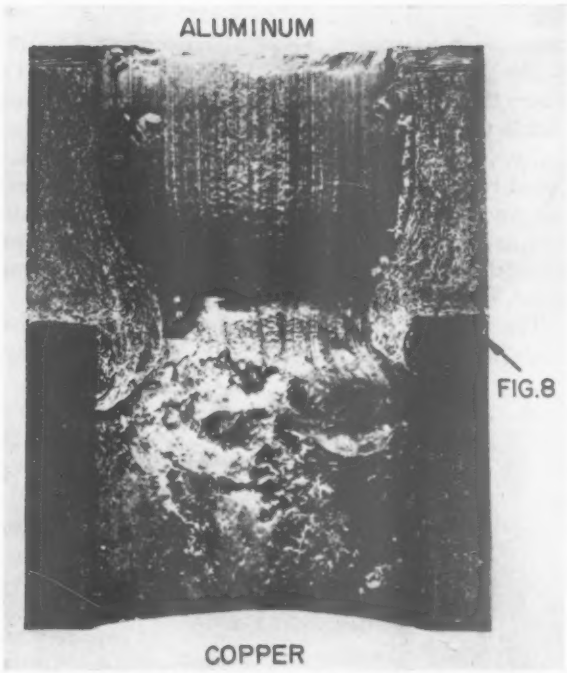

Fig. 7 Quality weld taken at 7 × showing correct upset formation in the aluminum. Nitric acid–ammonium persulfate and Kellers etch

Figs. 7–16 illustrate the value of metallographic examination for selecting optimum machine settings. These photos compare a quality joint with various types of defective welds. Emphasis is stressed on flow lines in the aluminum, continuity of the aluminum structure adjacent to the weld line and thickness of the alloy formation as a basis for comparison.

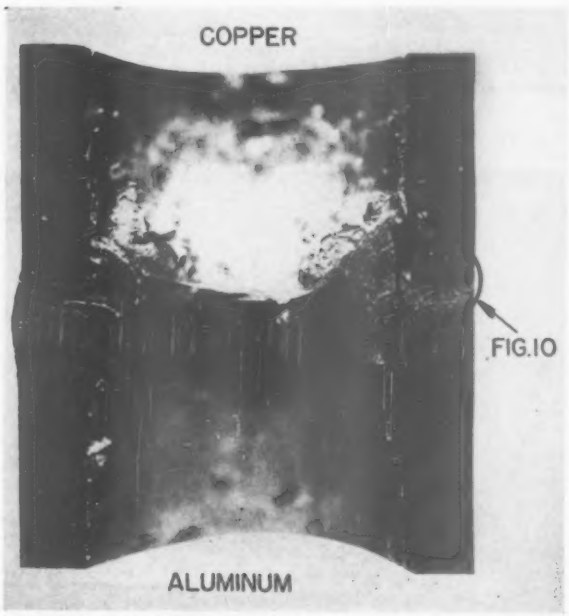

Fig. 9 Typical cold upset weld. Note flow line pattern in the aluminum mag. × 7

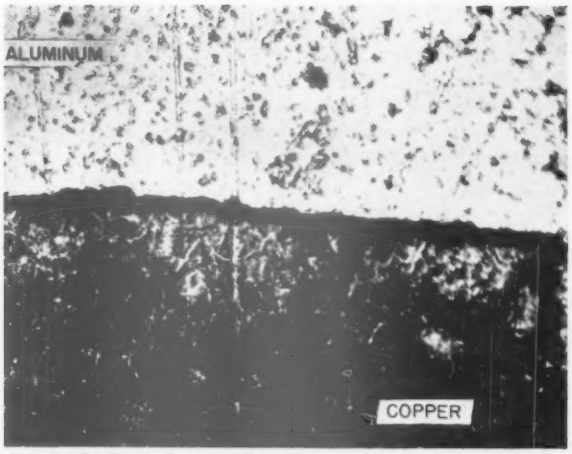

Fig. 8 Indicated area of quality weld in Fig. 7 taken at 250 ×

The photomacrograph in Fig. 7 of a quality joint shows that the proper temperature gradient has been established for upsetting because of the flow line pattern. The corresponding photomicrograph in Fig. 8 further shows that homogenous structure exists in the aluminum immediately behind the weld interface. Figure 8 also shows the alloy thickness which can be used as a comparative measure for subsequent photomicrographs.

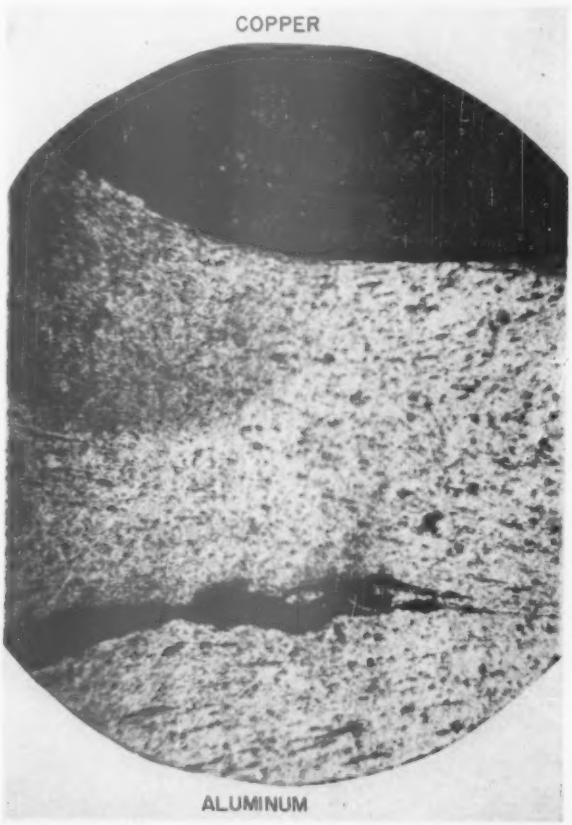

Fig. 10 Indicated area in Fig. 9 taken at 100 ×. Note parting line in the aluminum below the weld line

The photos shown in Figs. 9 and 10 are of a weld where the proper temperature gradient had not been established and consequently upsetting had taken place from behind the weld interface as shown by the sketch in Fig. 2. The photomicrograph shows cracks in the aluminum behind the weld line and also excessive alloy formation.

The photos in Figs. 11 and 12 are of a weld where the forging force was not applied through a sufficiently large dimension to completely remove cracks in the aluminum. Flow line distribution is good and the alloy formation is comparable to the quality joint in Fig. 7. This particular joint would have withstood considerable mechanical abuse but it may have shown up as undesirable on the basis of testing a large number of welds.

The photos shown in Figs. 13 and 14 are of a weld where the first pressure level was not of sufficient magnitude to accelerate the platen to the proper upset velocity. Heating due to upset current had been dissipated before the first pressure level was complete and the cracks in the aluminum were so extensive that it was impossible for the second upset pressure level to forge them together in the dimension that was provided.

The photos in Figs. 15 and 16 are of a weld that was made with the same machine settings as the quality

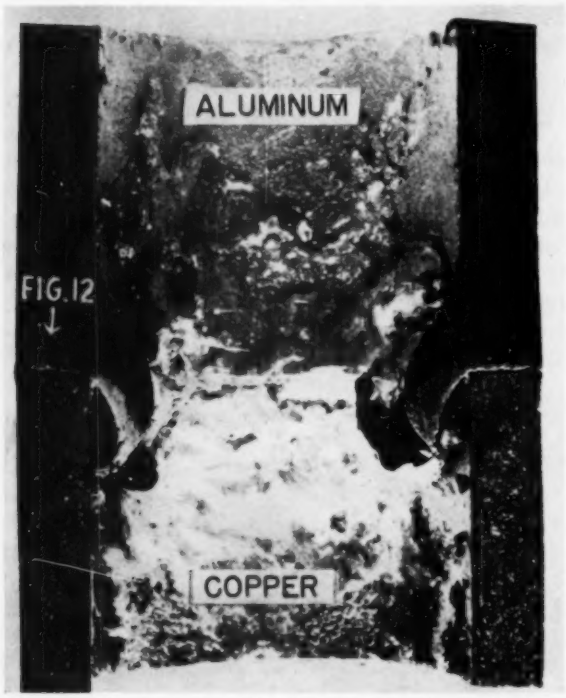

Fig. 11 Photomacrograph taken at 7 × of a weld where upset current magnitude was too high for the upset dimension and force selected for optimum operating conditions

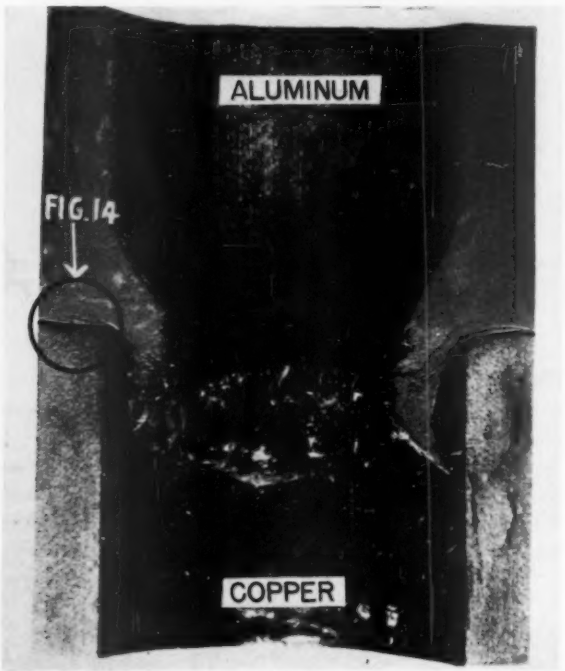

Fig. 13 Photomacrograph taken at 7 × of a weld where platen velocity was too slow during first upset pressure level

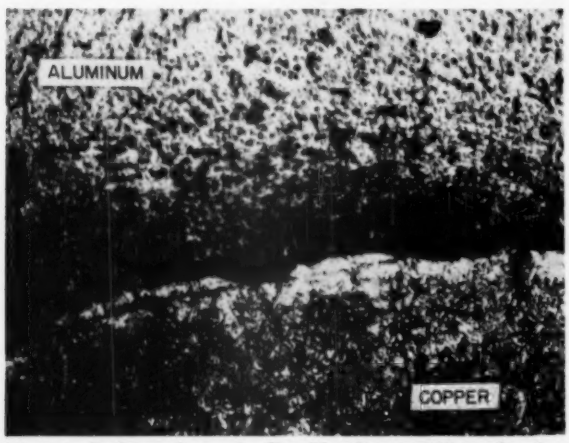

Fig. 12 Indicated area in Fig. 11 taken at 100 × showing defect in the aluminum adjacent to the weld line

Fig. 14 Indicated area in Fig. 13 taken at 100 × showing heavy cracks in the aluminum adjacent to the weld line

joint in Figs. 7 and 8 except that the platen was stopped by a positive mechanical means near the end of the first upset pressure level. The flow lines are good but the alloy thickness is excessively broad which indicates the importance of permitting the work to stop the forward motion of the platen at the end of the first upset pressure level. The appearance of the aluminum immediately behind the weld interface likewise illustrates the importance of the forging force to produce a homogenous structure.

COMPARATIVE WELDABILITY OF DIFFERENT TUBE DIAMETERS

Extensive welding analysis and consistency studies have particularly been concentrated on the $^{7}/_{16}$ OD size and it has been found that this size is less sensitive to variations such as upset dimension and upset current timing.

Upset current timing ranging from $1^{1}/_{2}$ to 4 cycles has been observed for the $^{7}/_{16}$ OD tubing without disturbing weld quality. It is more critical for the $^{5}/_{16}$ OD size and various studies have shown that it should be within a range of $1^{1}/_{2}$ to 2 cycles. It is important that the current must be cut off before the end of platen travel due to the first upset pressure level regardless of the tube diameter.

Joint consistency with less than 0.1% defective welds has been proved for the $^{7}/_{16}$ OD size on the basis of many thousand welds. A consistency report on the basis of extremely large quantities is not yet available for the $^{5}/_{16}$ OD but short runs indicate that it should be about as good as the $^{7}/_{16}$ in. diam.

USE OF SHIELDING GAS TO IMPROVE WELDABILITY

Inert gas, passed through the $^{5}/_{16}$ OD tubing at a low pressure during the weld period, has been found to better weld consistency but a report based on large quantities is not yet available.

It was found that the gas serves as a cooling media on the tube ID and effectively causes slight angular displacement of the weld line in such a manner that it forces a greater portion of the aluminum to the outside of the tube. The gas was also used to overcome random flash build-up inside the tube, at the weld line. This flash build-up sometimes acted as a shunt path to upset current and possibly affected current distribution about the weld periphery. The extent that it affects current distribution depends on how well the flash makes contact with the tube inner wall, the amount of flash making contact and the degree of oxidation.

Gas flow was directed so that it entered the free end of the copper and was exhausted through the free end of the aluminum. It was noted that molten metal was blown out the aluminum end when a steady flash was established. Such welds were found to be free of random flash build-up on the inside of the tube, and

Fig. 15 Photomacrograph taken at 7 × of a weld where the forward motion of the machine platen was stopped by a positive mechanical means near the end of the first upset pressure level

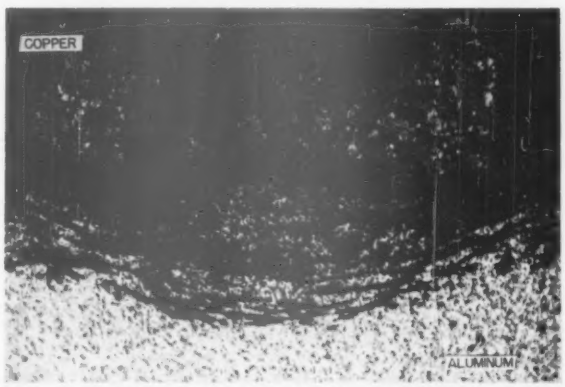

Fig. 16 Indicated area in Fig. 15 showing numerous cracks in the aluminum and excessive alloy formations at the weld line magnification 100 ×

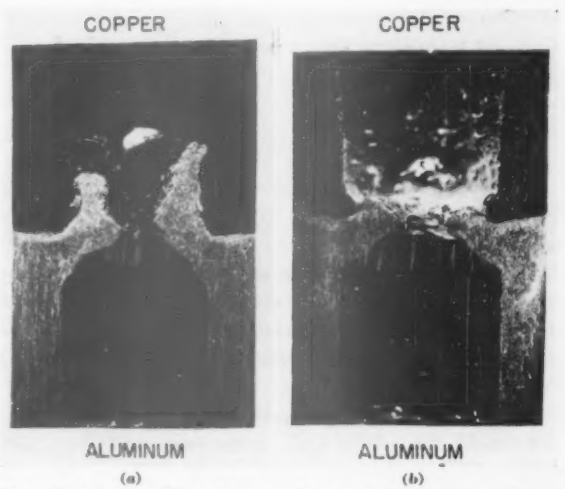

Fig. 17 (a) $^{5}/_{16}$ OD tubing welded without internal gas flow. (b) $^{5}/_{16}$ tubing welded with internal gas flow. Note that upset formation is less than (a) and angular displacement of weld line. Magnification × 7

Fig. 18 Photomacrograph showing the effect of misalignment on one side only. This was done by deforming the copper end prior to welding. Magnification ×7

only upset metal of a definite pattern remained. A photomacrograph of a weld made in $^{5}/_{16}$ OD tubing with the use of gas is shown in Fig. 17(*b*). A photomacrograph for a weld made with the same machine settings but without the use of gas is shown in Fig. 17(*a*) for comparison.

Argon gas was extensively used for this investigation but it is felt that most any neutral gas would be satisfactory. Gas pressures of $2^{1}/_{2}$ to 3 psi were found to be optimum. Pressures lower than this were not effective to the desired degree. Higher gas pressure hindered flashing to the extent that it caused freezing and stalling.

PINCH-OFF DIES

Pinch-off dies made from hardened steel and Class 2 copper alloy with 10W53 Elkonite cutting edges have been extensively used for this application. The sharp cutting edge and the angle of the cutting face makes it possible to cut free the external upset metal at least to the extent that it is easily removed by a simple stripping operation. A typical set of pinch-off dies is shown in Fig. 1.

It has been found that steel dies do stand up better but the flash tends to stick to the exposed faces which makes their usage more troublesome. Flash does not stick to the Elkonite faced dies.

Elkonite faced dies will last approximately 25,000 welds as compared to 40,000 or 50,000 welds with steel dies. The cutting edges of Elkonite faced dies are easily restored by refacing in a lathe but grinding is required for the hardened steel dies.

It should be realized that if upset current time is too long, it is possible for the joint to blow out near the end of the upset and cause damage to the cutting edges. It is also necessary that a positive mechanical stop be provided on the movable platen to prevent the possibility of jamming the ends of the dies together.

The previously mentioned weld schedules designate initial extension of the copper as $^{1}/_{16}$ in. Extensive studies concerning what this dimension should be have shown that a range of $^{1}/_{32}$ to $^{3}/_{32}$ has no effect on weld quality. However, it was found that shorter extensions do cause more rapid deterioration of the cutting edges on the dies that grip the copper.

The macrophoto in Fig. 7 shows the flow lines for a weld that was made with good alignment of the welding dies. Misalignment will disturb flow line pattern since upset pressures will no longer be normal to the weld interface. Current densities will then be greater since the effective weld area has been reduced. It can therefore be realized that weld quality will suffer according to the extent that misalignment of the welding dies exists.

The photomacrograph in Fig. 18 is of a weld where one side of the copper was purposely deformed prior to the welding. This photo shows that the flow line pattern in the aluminum was drastically affected on that side where the copper was deformed.

WELDING EQUIPMENT

Figures 19 and 20 show the welding machine that was used in the included weld schedules. It is model B-3-D rated at 30 kva and manufactured by the Taylor-Winfield Corp.

The forward motion of the platen during flashing is actuated by a motor-driven cam which determines the acceleration rate during the flashing cycle. The amount of flash off is controllable by a vernier adjustment that serves to select the desired working ratio of the rise that is provided on the flashing cam. A Reeves Variable Speed Drive is used between the motor and gear reduction unit to vary cam rpm and thus select the desired flashing time. A solenoid operated clutch is incorporated in the gear reduction unit which allows the motor to operate continuously.

Additional timing cams for operation of the clamps, initiating the weld current, cutting off the weld current and operation of the air upset mechanism are also secured to the same shaft that rotates the flashing cam.

An indicating dial is likewise secured to the timing shaft and it is calibrated to indicate when each portion of the mechanism operates. Oscillographic equipment is extremely helpful when first setting up a machine but further usage should not be necessary once the indicating dial is calibrated. If trouble should occur with timing in the sequence of operation, it is merely necessary to rotate the timing shaft by hand and

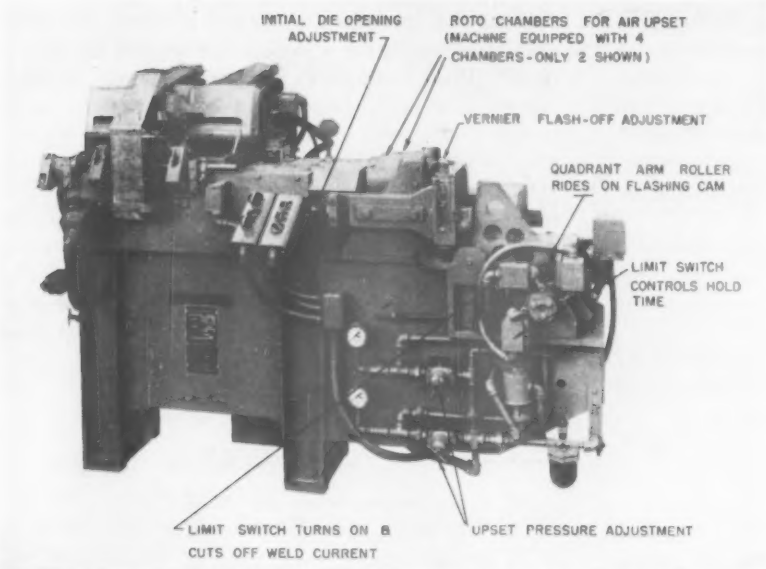
INITIAL DIE OPENING ADJUSTMENT
ROTO CHAMBERS FOR AIR UPSET (MACHINE EQUIPPED WITH 4 CHAMBERS - ONLY 2 SHOWN)
VERNIER FLASH-OFF ADJUSTMENT
QUADRANT ARM ROLLER RIDES ON FLASHING CAM
LIMIT SWITCH CONTROLS HOLD TIME
LIMIT SWITCH TURNS ON & CUTS OFF WELD CURRENT
UPSET PRESSURE ADJUSTMENT

Fig. 19 Motor-driven air upset machine that was used for the included weld schedules

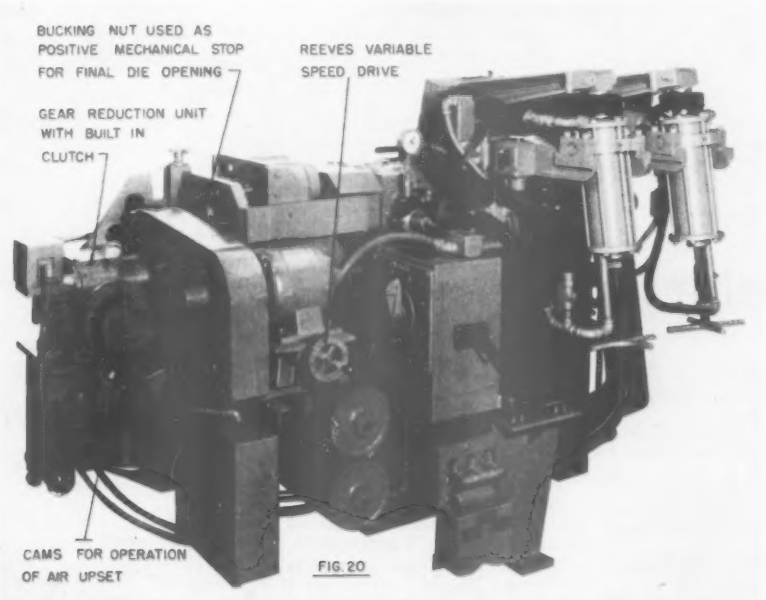
BUCKING NUT USED AS POSITIVE MECHANICAL STOP FOR FINAL DIE OPENING
REEVES VARIABLE SPEED DRIVE
GEAR REDUCTION UNIT WITH BUILT IN CLUTCH
CAMS FOR OPERATION OF AIR UPSET
FIG. 20

Fig. 20 Rear view of machine shown in Fig. 19

observe if each operation is in accordance with the indicating dial.

The machine was equipped with a double-pressure air upset mechanism where upset pressures are applied by exhausting air from restraining air cylinders. Independent adjustment is provided for each pressure level by regulating air pressure. Operation of the air upset is controlled by cams secured to the same shaft that rotates the flashing cam but the flashing cam has no control over platen travel once the upset mechanism is initiated.

The machine frame is of rigid construction to avoid deflection and the movable platen was accurately guided to maintain positive alignment of the welding dies. The weight of the movable platen had purposely been kept at a minimum to permit fast acceleration by the application of comparatively light pressures so that the work can stop the forward motion of the platen at the end of the first upset pressure level.

Aluminum will more readily deform than copper when clamped but the extent of permanent deformation for copper is the greater. This means that the copper tubing is generally the more difficult to hold from slipping. It is therefore desirable that independent clamping pressure adjustment be provided because of the described difference in elasticity.

Impact on the work due to air clamps can readily cause permanent deformation on the copper and effectively cause slippage. Backups have been employed to prevent slippage where short lengths are involved and they also provide a means for controlling material extension from the dies when the work is cut within close tolerance limits.

Backings are not practical where long lengths are involved and air-operated clamps with an adjustable closed position have been used with success. This provides a means to overcome the effect of permanent deformation due to impact.

Where backings are not employed, a spacer or gaging bar is used as a guide for loading the work in the dies with the proper extensions. This spacer bar is also sometimes used to unload the welded joint as in fully automatic machine operation.

WELDING IN PRODUCTION

Several manufacturers of refrigerators have such equipment in production and by proper maintenance and supervision have learned that a maximum of 800 joints per hour at 100% efficiency on a fully automatic machine can be expected; that is, where the operator is required only to load the tubing and start the machine. This is for Elkonite faced dies since flash tends to adhere to the exposed faces of steel dies as mentioned above. It is also assumed that the fully automatic machine has provision to remove loose particles from the dies after each weld by an air blast.

Proof or nondestructive testing is being employed on one production line with automatic equipment for reverse bend testing welds made in $^{7}/_{16}$ OD tubing. This test consisted of bending the joint 7 deg in two directions with respect to the original axis. Pressure testing is then used to determine if any joints are defective. Proof testing is generally conducted after the internal upset has been removed.

In some instances, reverse bending in four directions has been used for proof testing welds in $^{5}/_{16}$ OD tubing. The extent of each bend was 6 deg with respect to the original axis.

The object in either method is to bend the joint to the extent that welds of inferior quality can be detected and still not destroy a joint of satisfactory quality.

CONCLUSION

It can, therefore, be concluded that flash welding with suitable equipment is a practical process for joining copper to aluminum tubing. The process can be described as economical since production rates are exceptionally high with joint consistency of better than 99.9%.

It may be questioned: why is it necessary to bother with proof testing for a joining process that has proved itself? Proof testing does insure that the equipment is operating correctly, the work is being properly loaded in the welding dies and that the condition of the dies and die alignment is satisfactory.

The included weld schedules that are given should serve as a tentative guide for other tube diameters and wall thickness that may be considered. It is further thought that the general technique should be applicable to any joint in these two metals where the highest quality welding is required regardless of the sectional shape that is involved.

APPENDIX

All experimental work for both $^{7}/_{16}$ in. OD and $^{5}/_{16}$ in. OD tubing sizes was done using 3SO aluminum. It is for this reason that material specification was stated accordingly. Since that time, various manufacturers of refrigerators have reported better consistency with 2SO aluminum on the basis of extremely large production figures.

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(*Continued from page 1161*)

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The Production of Welded Stainless Steel Pipe

Procedures for production welding, radiographing welds, heat treatments and inspection in the fabrication of stainless steel piping up to 7/16 in. thick and 14 in. in diameter

by A. Grodner

ONE of the prime needs of the Atomic Energy Commission for its Savannah River Atomic Hydrogen Plant was stainless steel pipe for conveying gases, liquids and radioactive waste products at high pressures, high temperatures and under various degrees of corrosive action. The size of this required stainless steel pipe, in many areas, was beyond the maximum size limits of the seamless pipe mills, and thus the Atomic Energy Commission was obliged to turn its attention to the production of welded pipe.

Alloy Fabricators Division of Continental Copper and Steel Industries, Inc., at Perth Amboy, N. J., was one of several stainless steel fabricators who was invited to participate in this production program, and it immediately set about to gear its engineering and production personnel and facilities to meet the urgent demand for this welded pipe. Not only was the highest quality of workmanship a prerequisite, but speed of production was even more imperative.

There were no established specifications for the actual fabrication of this welded stainless steel pipe at the time the contracts were let. True, ASTM Specification A312–48T included the term "welded pipe" along with "seamless pipe," but a fabricator could find there paragraphs dealing only with the chemical analysis of the several grades of stainless steel, their physical properties, the tolerances in diameter, ovality, weights and wall thickness, the requirements for hydrostatic testing, flattening tests, etc. It was, therefore, necessary to develop procedures for welding, for the radiographing of the welds, for the heat treatment of the finished pipe and for the pickling, corrosion testing and final inspection.

The pipe which we were asked to produce, ranged in size from 3 to 14 in. (Schedule 10 and Schedule 40) having wall thicknesses of 1/8 in. for the smaller Schedule 10 pipe to 7/16 in. for the larger Schedule 40 pipe. Most of the pipe was to be made of Type 304L (18/8 chrome nickel, with 0.03% maximum carbon) and some

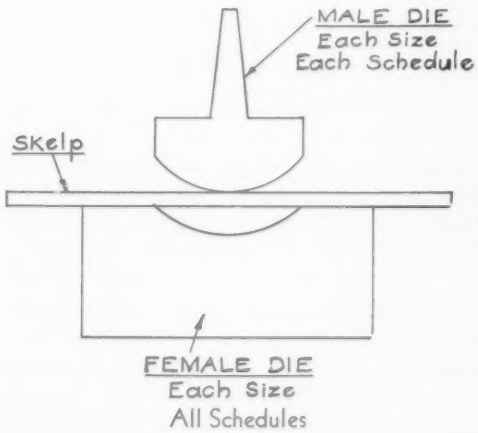

Fig. 1 Forming die

of Type 309 Cb (25/12 chrome nickel, stabilized with columbium). All pipe was to be made in 10-ft lengths.

To launch this production program in our shop, it was necessary to design and prepare forming dies to shape the pipe, welding jigs to hold the pipe and weld the seams, modify our furnace for the proper heat treatment of the finished pipe, install pickling and passivating tanks, provide facilities for the radiographic inspection of the welds and for the hydrostatic testing of each length of pipe. We were also obliged to maintain a complete identifying history of each length of pipe, from the initial heat number of the plate from which it was formed, to the final heat-treating furnace lot number at the completion of that length of pipe, through its final testing, inspection and shipment.

Let us follow the various steps in the production of this pipe from the flat plate, known as "skelp" at the mill. We asked the mills to supply this skelp in lengths of 120 in. and in widths equal to the mean circum-

Fig. 2 Preformed pipe section

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Presented at the AWS National Spring Meeting held at Buffalo, N. Y., May 4–7, 1954.

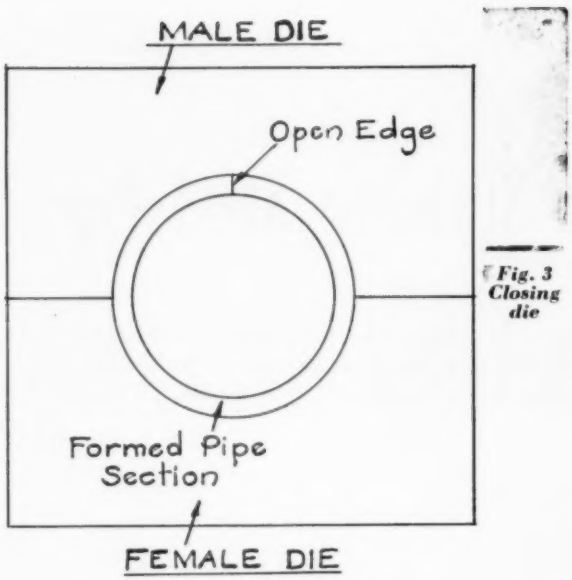

Fig. 3 Closing die

ference of the pipe; that is, the average of the inside and of the outside circumference. We further specified that the 120-in. edges must be parallel, so that the formed pipe could be held to the required diameter tolerances. A further specification informed the mill of the maximum over and under the nominal thickness, to comply with the ASTM rules.

The skelp thus rolled at the mills was finally annealed and pickled prior to its shipment to us. Simultaneously, a coupon representing each heat and each heat-treated lot was forwarded by the mill to the DuPont Laboratories for corrosion evaluation by the Standard Boiling Nitric Acid Test, the well-known Huey Test, in accordance with ASTM Spec. A262. If this test, after five 48-hr exposure periods, indicated an average corrosion rate not exceeding 0.002 in. penetration per month, the skelp was accepted and released to us for fabrication. Thus, the skelp shipped to us by the mills was correct as to chemical analysis, physical properties, corrosion evaluation, size and thickness, within the prescribed limits. Plates which failed the corrosion

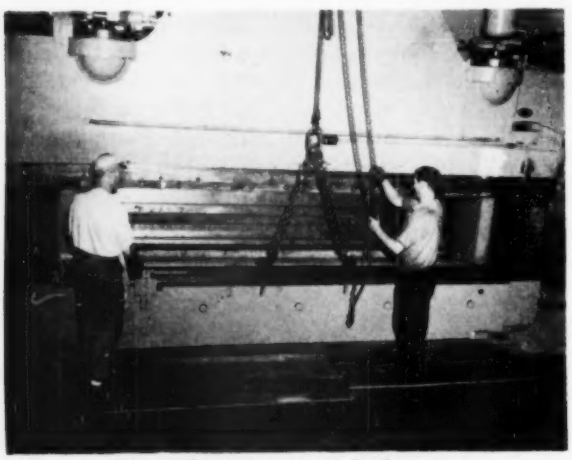

Fig. 4 Forming pipe in brake press

Fig. 5 Automatic welding of pipe

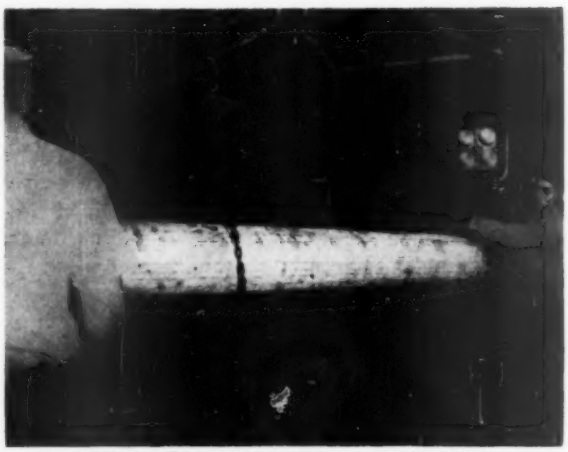

Fig. 6 Removing pipe from welding jig

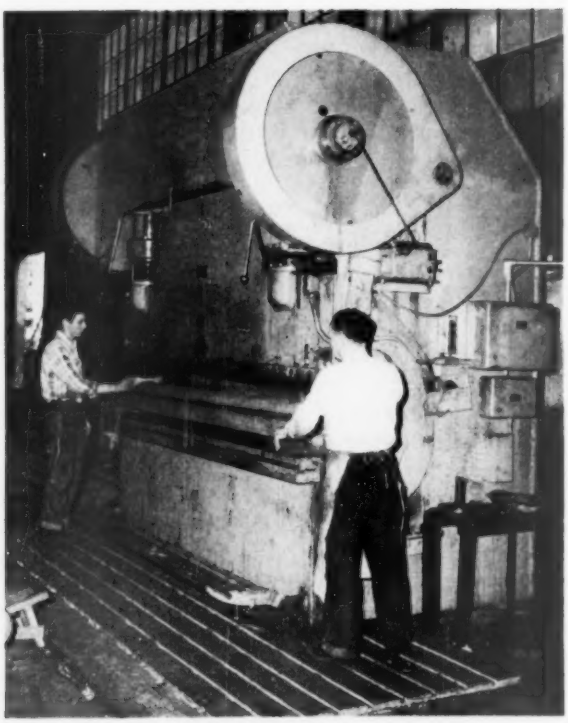

Fig. 7 Straightening pipe after heat treating

Fig. 8 Trimming ends of pipe

Fig. 9 Grinding imperfections

test (presumably, because of incorrect heat treatment), but which were chemically correct, were reheat treated by the mill, and in some cases (to save time) released to us for fabrication on the assumption that our own heat treatment of the finished pipe would correct the corrosion resistance quality to the required value.

The skelp received was now ready for forming, without any further preliminary steps. All pipe was formed in our brake press, which has a 16-ft bed, is capable of exerting 450 tons pressure, with an equivalent capacity for bending steel plates up to $^{9}/_{16}$ in., 12 ft long to a 90-deg angle. For each size pipe (which includes all wall thicknesses, since they have a common outside diameter) a female forming die is installed in the press. A separate male die must obviously be employed for each wall thickness of each pipe size, since the inside diameter varies. The pipe is formed by manually guiding the skelp progressively through the dies, an average of 5 steps, to the approximate shape, open at the top, as shown. This preformed pipe section is then closed to the correct contour and required dimensions in a second set of dies, or closing dies. One set of closing dies is needed for each pipe size. Here again, one set of dies handles all schedules of each size of pipe. These closing dies were used for pipe sizes up to and including 6 in., where the formed pipe were closed tightly. For pipe over 6 in. size, closing dies become too large for the press, and therefore, the forming dies only were resorted to, and the pipe was rounded to shape, with about an $^{1}/_{8}$-in. gap. The male die descends approximately every $^{1}/_{2}$ in. to final contour.

The formed pipe, without any weld bevels, is next delivered to the welding jig. Here the pipe is gripped, for its entire 10-ft length, within two half-round shoes, one half of which is fixed, the other moved and held in position by hydraulic pressure. Each size pipe requires an individual shoe. The pipe seam is exposed at the top. With the pipe thus held, no tack welds are required. The advantages resulting from this omission of the tack welds are twofold—the saving of considerable production time, and the avoidance of the discontinuity of the welding process, so important in high-quality welding.

Welding of all pipe was accomplished by the shielded inert-gas metal-arc process, with consumable electrode, known as "sigma" welding. Bare wire on a reel, together with argon gas, is delivered to the welding head; a water cooled copper backing element, inside the pipe, travels simultaneously with the welding head. Throughout the travel of the welding head over the length of pipe, argon gas protects the weld on the outside, and helium gas, fed through the backing element, protects the weld metal on the inside. The weld wire is normally $^{1}/_{16}$-in. diam, type No. 308 ELC or No. 347 for the type No. 304 ELC pipe and type No. 309 Cb for the corresponding pipe. Argon gas flow was maintained at approximately 50 to 60 cfh through the welding head; helium gas through the backing element at about 1 to 2 cfh. All pipe sizes, up to and including 14-in. Schedule 40 (having a wall thickness of $^{7}/_{16}$ in.) were thus welded in one pass—Schedule 10 pipe at the rate of 23 to 30 ipm, Schedule 40 pipe at the rate of 18 to 27 ipm, depending upon the size. The welds produced were of uniform width, depth and quality over the entire length of pipe, and with a minimum crown above the pipe surface; the weld projection on the interior of the pipe was held to $^{1}/_{32}$ in. max.

Radiographing of the welded seam was a principal requisite for this welded pipe project. The specifications called for 100% examination of the first 50 ft of each size, for the particular setup of the welding machine and procedure. Upon acceptance of these radiographs by the A.E.C. inspectors, the remaining pipe of that size was similarly examined to the extent of approximately 5% of the total chosen at random by the inspectors.

The pipes to be radiographed were transported to the X-ray room, in a remote section of our shop. There a 200-kv unit exposed the films placed over the welded seams. For pipe 6 in. and over in size, the film holder was inserted inside the pipe for exposure through the weld onto the film; for smaller pipe, the film was placed on the outside of the seam, and the X-ray directed through the wall of the pipe opposite the film. Any defects discovered by these radiographs were of course ground out, rewelded, and re-examined as before.

The pipe was now ready for heat treatment. To restore the metal to its maximum corrosion resistance, all pipe was given the full solution heat treatment, by heating them to a temperature of 1950–2050° F for a period of time varying from 15 to 30 min, depending on the wall thickness, and immediately water quenching them. About 40 lengths of pipe were loaded on two racks (made of heat-resistant alloy), the two racks in line along the length of the furnace, on the floor of a car-type, oil-fired furnace, equipped with accurate temperature controls. At the termination of the heating cycle, the pipes were released from their racks, which have a slight slope, and allowed to roll into a pit filled with water, set alongside the furnace. They were thus quickly and uniformly cooled through the critical temperature range as recommended for the austenitic grades of stainless steel.

To check the corrosion resistance of the heat-treated pipe, a record was maintained of the specific pipe sections which were charged in each furnace lot, and one or more rings cropped from the ends of pipe in each charge as directed by the inspectors. These pipe rings were then sent to the DuPont Laboratories for corrosion evaluation, which was a repetition of the test imposed upon the original skelp. Any sample which failed to exhibit the proper corrosion values was interpreted as representing either improper heating or improper cooling, and the heat-treatment cycle for all the pipe in that furnace lot was repeated. Fortunately, such operation was required for only about three furnace lots out of more than 250.

While the corrosion coupons were being subjected to the boiling nitric acid tests for five 48-hr periods, we continued with the final steps in the series of fabricating operations. Immediately after heat treating each lot of pipe, the individual pieces were returned to the brake press for straightening and rerounding. Pipe up to and including 6 in. size was straightened and rounded with wooden blocks inserted in the male tee bar, while the pipe was held in the female closing die; pipe 8 in. and over was similarly treated in the female forming dies.

Following this work, bundles of pipe were immersed in wooden pickling tanks, containing 15% nitric acid and 3% hydrofluoric acid (by volume) at a temperature of approximately 85° F., held within the pickling solution for periods ranging from one to one and a half hours, and then rinsed with water under pressure.

With the oxide film thus completely removed from the inside and outside, the pipe lengths were taken to a special lathe where their ends were cropped to produce a square edge. This finished edge was not only required by the inspectors, to facilitate field welding, but it enabled us to maintain an adequate seal for the hydrostatic testing operation which followed. Each length

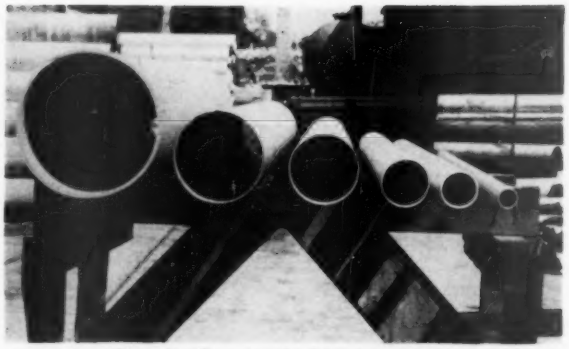

Fig. 10 Pipe stacked for inspection

of pipe was given a hydrostatic test equal in magnitude to that determined by the formula in ASTM Specification A312:

$$P = \frac{2St}{D}$$

where

P = hydrostatic test pressure, psi
S = allowable fiber stress (50% of min. yield strength, or 12,500 psi for the low-carbon grade of stainless steel)
t = nominal wall thickness, in.
D = outside diameter of pipe, in.

Thus, a 6-in. Schedule 40 pipe was subjected to a hydrostatic pressure of 1060 psi, while a 14-in. Schedule 40 pipe was tested at 780 psi. Obviously, the lighter Schedule 10 pipe sustained lower pressures. The lengths of pipe, held against rubber gaskets on the face plates at each end of the testing machine, were maintained at the required pressure for an average of two minutes' duration, while the inspector checked the seam for possible leaks.

The pipe was now ready for the final inspection. The internal and external surfaces of each piece of pipe were carefully examined for seams, laps, tears, scale, pits or other defects. Minor surface defects were corrected by grinding, provided the wall was not thereby reduced below the minimum allowable thickness. The straightness and roundness of the pipe came under close scrutiny, especially because of the field welding requirements. The OD of pipe up to 4 in. inclusive, was maintained at $\pm 1/32$ in.; over 4 to 8 in. inclusive, $+1/16$ in., $-1/32$ in.; over 8 in., $+3/32$ in., $-1/32$. The interior weld projections were held at $1/32$ in. max. The inspector also checked the heat number and furnace lot number, stamped on each pipe.

The pipe, upon being released by the inspector, was finally passivated in a solution containing 30% nitric acid at 130° F and then rinsed in warm water. It was now ready for shipment to the field.

Welded TV Tower

Fabrication and erection of 1572 ft TV tower are sparked by faster welding

by Robert A. Vaughn

DESIGN and execution of a 660-ton triangular section "steel needle," extending nearly one-third of a mile straight up into the pleasant Oklahoma air, called for some highly specialized talents on the part of engineers, fabricators and erection crews. Claimed to be the tallest man-made structure on the face of the earth, it is a 1572-ft guyed TV tower for mounting two television antennas to be operated by Station KWTV of Oklahoma City, Okla.

Thanks to the unique combination of high-speed manual shop arc welding in precision jigs and a novel design of 100-ft electric gin pole for hoisting partially assembled sections into place for bolting together, it has been possible to maintain a steady flow of steel through the fabricating shop on to the tower site and up into position. Result: the job has been kept continuously on schedule and the christening date established early in the year was met easily by the erection subcontractors, Mizell Construction Co., Ganado, Tex.

A specialist in the design of radio and television towers, the Ideco Division of Dresser-Stacey Co., Columbus, Ohio, had no qualms over undertaking the design of this grandaddy of them all. Previous Ideco towers have been in the 800–1000 ft height range, but the desire for maximum television coverage—and perhaps a native pride in having the nation's biggest—led KWTV planners to invest close to $500,000 for the ultimate in towers and transmission equipment. Contemplated signal radiation intensity is 316-kw video and 158-kw audio, emanating from two antennas, one atop the other, tuned to channels 9 and 13, respectively. Line-of-sight distance to the horizon from the tower top is 60 miles. This is the normal effective signal range in all directions, although atmospheric conditions may push it well beyond that.

To understand the specialized fabricating problems involved, it is necessary to have in mind the general physical characteristics of the tower structure. It is straightsided with 12 ft face and three vertical legs forming the triangular section. The legs are made in sections, most of them 30 ft in length and are tied mutually together by horizontal girts of steel angles and diagonal bracing of steel rounds, bolted to drilled gusset or wing plates which have been welded to the leg members. The latter are joined together vertically in the field by means of heavy circular flanges welded to each end and drilled to receive eight heavy bolts each.

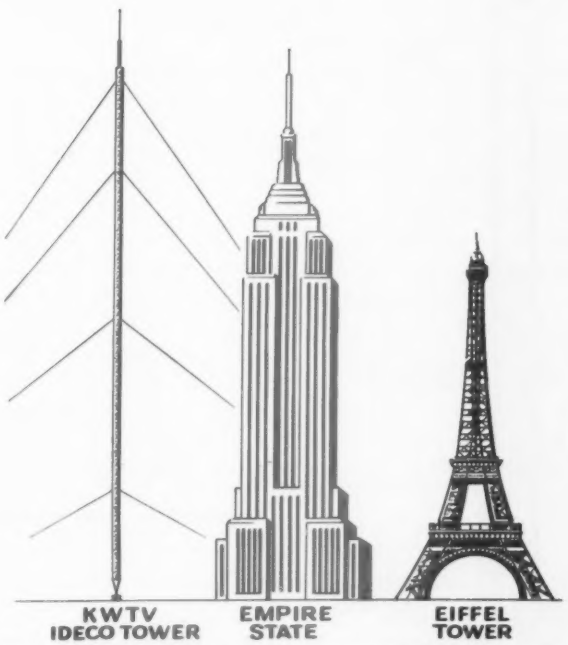

Fig. 1 Artist's sketch showing approximate height relationship between 1572-ft TV tower and two other well-known tall structures

The tower structure itself extends upward some 1420 ft, and at its peak is additional structural steel framing to support the lower antenna, 79 ft in height. Above that is the second antenna, 73 ft in height. The entire assembly rests on its "lower point" so to speak, on a reinforced concrete base surmounted by a 36-in. diam porcelain insulator capped by three $5^1/_2$-in. thick steel slabs carrying the tower's base.

There is a total of 54 individual sections stacked up for the complete tower. All structural members are machined, welded, galvanized and painted in the Columbus tower shop and then rail shipped knocked-down to Oklahoma and bolted together, piece by piece, on the ground and in the air.

Robert A. Vaughn is Director of Engineering, Ideco Division, Dresser-Stacey Co.

Perhaps the most spectacular feature of the design is the size and weight of the leg sections. The lower 30 ft comprises three $10^1/_2$-in. diam solid forged steel rounds, tapering together at the base to form the pivot support. The next 270 ft are made up of nine sections, each 30 ft long with legs of 14-in. wide flange H-beams weighing 314 lb to the foot! These are undoubtedly among the heaviest sections ever to be rolled, and they weigh a neat 9300 lb each. They are tied together by girts and diagonals plus the end flanges, the same as are the round legs.

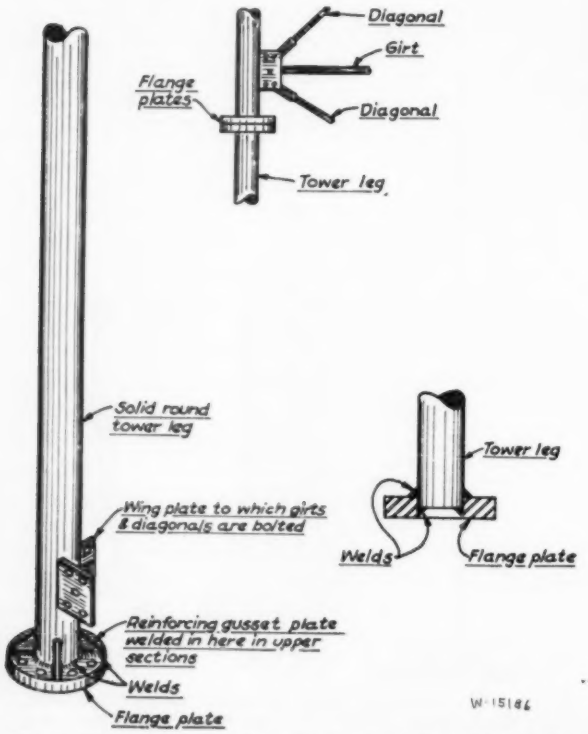

Fig. 2 Wing plates and flanges are manually welded to the solid tower leg being drilled as shown for splicing the leg sections by bolting and for attachment of horizontal girts and diagonal braces. Flange welds in upper leg sections subject to possible reversal of stress due to wind pressures are strengthened by the insertion of gusset plates between flange and leg

Next come two sections of $9^1/_2$-in. rounds, designed particularly heavy because they carry the attachments for the lowest set of guy cables. Then there are 35 sections, each 30 ft long, with 8-in. round legs, stepping down to 6-in. rounds toward the top. Finally there are three 20-ft "bays" having 4–5 in. rounds and above them the antenna support framework built up of 8- x 8- x $1^1/_8$-in. angles, these of low-alloy, high-tensile steel. The 35 intermediate sections also are of this higher strength steel while all other members are of mild steel either SAE 1020 or ASTM A-7 specification. All bolts are alloy steel.

At the 290-, 650-, 1040- and 1340-ft levels heavy welded steel collars carrying guy cables are fitted in place. At each level there are three pairs of guy cables fanning out 120 deg apart to anchorages on the ground.

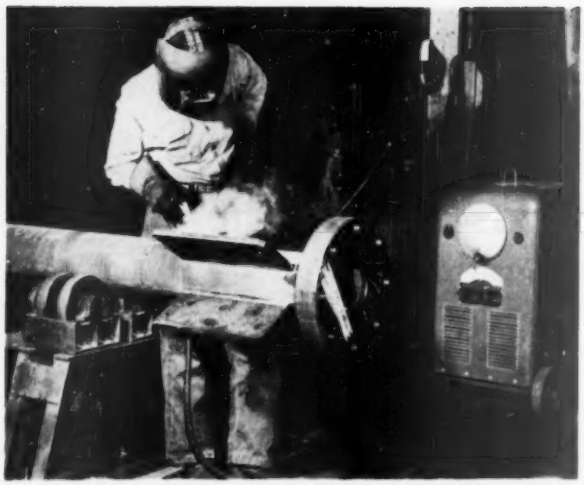

Fig. 3 Fillet welds on the wing plates are made with high-speed coated electrode of $^3/_{16}$-in. diam and at a current setting of 275 amp a-c generator being shown in background. Plates are $1^1/_2$ in. thick, leg member 7 in. round

The latter are positioned 950 ft from the tower base for the upper three sets of cables, 520 ft for the lower set. Each pair of cables is attached to the two tower legs on that face, running parallel down to the anchoring point.

Reinforcing steel in tower and guy anchor bases weighed in at 30,000 lb, and it is embedded into 1200 cu yd of concrete sunk into the ground. The 24 guy cables have a total length of 27,000 ft and aggregate 267,000 lb. They are all prestressed galvanized bridge strand cable. The top six are 2 in. diam with rated breaking strength of 490,000 lb. Each of the six lengths carried five Lapp porcelain cable insulators. Insulators are unequally spaced to prevent harmonic vibrations. At the 1040-ft level the cables are $1^7/_8$ in. diam and are provided with four insulators along their

Fig. 4 Welding inside the end flanges using Jetweld 1 welding rod of $^1/_4$ in. diam at 350 amp ac. Rotation of the leg in the jig is controlled by the switch convenient to the operator. In heavy leg sections as many as 40 or 50 passes are made to complete the fillet weld

lengths. At the 650-ft level the cables are $1^5/_8$ in. diam also with four insulators each and at the lowest level $1^1/_2$ in. diam with two insulators.

Prestressing of the cable is done by the manufacturer. One end is attached to jaws on a car which is run out a track to the length of the cable. The other end then is pulled taut in a hydraulic mechanism similar to a large tensile testing machine. The cable is stretched to just under the yield point, thus eliminating locked-up stresses and insuring a minimum of "give" when installed.

The heavy insulator supporting the tower is of unusual construction. It has 21 individual porcelain elements, each $6^1/_2$ in. diam with an I.D. of $3^1/_2$ in. and weighing in all 4600 lb assembled into circular form. A steel cap of 36 in. diam and $5^1/_2$ in. thick is placed on the head of the insulator, with a lead gasket between the head and the cap. The latter is held to the insulator by six $1^3/_4$-in. bolts. Temporary tierods join the cap to the steel base, permitting preloading of the insulators to 300,000 lb to avoid danger of transverse load affecting the insulator during erection. Once the weight of the tower is taken up by the insulator, the tierods can be removed. Each of the cylindrical insulator sleeves is filled with oil to make it more effective in preventing electrical radio frequency losses.

At maximum working load, each porcelain sleeve carries 134,000 lb, equivalent to 5700 psi, which is exceptionally low for radio insulators. Where thermal stress is not present, porcelain will show compressive strength of well over 35,000 psi, giving a safety factor of well over 4 : 1 in this instance. Total tower weight on the insulator is 1,323,392 lb or over 660 tons. Actually, it is designed to withstand crushing load of 5600 tons with a maximum working load of 1400 tons.

In case of breakage or other difficulty with the insulator platform once the tower is in service, it is possible actually to "lift" the weight of the tower off the insulator through manipulation of three hydraulic jackposts, shown in one of the illustrations. They are positioned

Fig. 5 Smooth and clean 1-in. fillet weld on the outside of the flange requires virtually no cleaning by virtue of the good wash-in and slagging properties of the Jetweld rod which has powdered iron mixed with a refractory coating

Fig. 6 Drilled and slotted end plates are welded to 2-in. round diagonal braces, length being maintained accurately by means of locating pins on the jig which hold the end plates firmly to compensate for slight variations in lengths of the round bars

squarely under the three tower legs at the point 30 ft up where the main legs begin to converge to join at the insulator base. These posts are triangular in section, with three legs of 4-in. steel rounds and having a face spacing of about 14 in. They are tied together with a lattice of diagonal round bars and plates, all prefabricated by welding before erection. The three posts are spaced 12 ft apart and meet the main tower legs at the point where the H-section columning starts.

Because of the weights and wind factors involved, a tower of this magnitude is subject to tremendous stresses. Some design loads run well over 500,000 lb. Specifications call for meeting wind loads of 60 psf of projected area on the upper 792 ft of the tower, and of 40 psf of area on the lower 780 ft. These loads are tempered somewhat by the use of round leg sections and diagonals, which means that they can be reduced, in effect, by one-third.

At numerous points in most towers, particularly those which are not guyed at the top, the welds and, of course, the tower members are liable to a reversal of stresses from compression to tension and vice versa, as the wind changes direction. Tension develops in members which are deflected or "bowed" slightly by the wind pressure between the fulcrums of guying points.

Lower tower sections, because of the high axial compression induced by the "pull-down" effect of the guy cables and the weight of sections above, are not deflected to any important extent by wind and, hence, are loaded probably 90% in axial compression.

In the upper bays where there may be stress reversal, the end flanges are reinforced by gusset plates welded to them and to the legs as shown in one of the sketches herewith. In lower sections under high axial compression loading, precautions are taken to prevent the legs from punching through the flanges.

In some cases a varying wind pressure loading is computed in the design of a special tower. For example, on a 1057-ft tower built in Milwaukee, Ideco engineers figured a wind pressure of 70 lb at the top, tapering to 30 lb at the bottom. Again these loads are reduced by the use of round structural sections.

Before turning to some of the shop welding detail, a few other facts on the KWTV tower may be of interest. Inside the structure and supported therein are

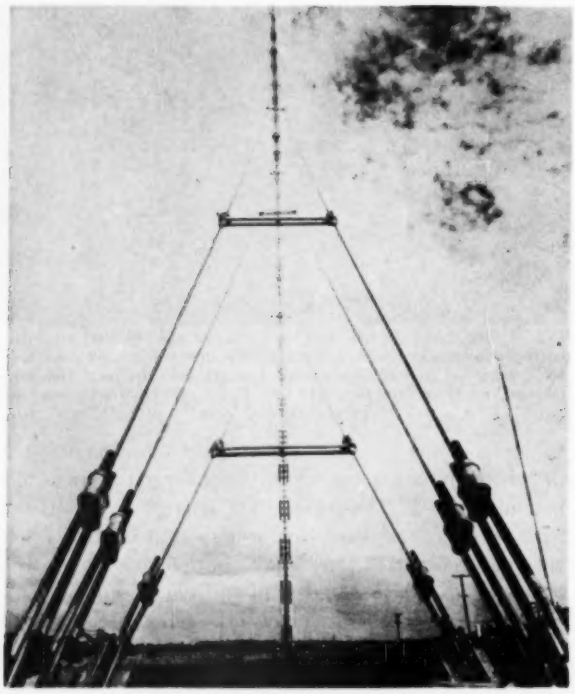

Fig. 7 Completed tower which was raised in only 9 weeks' time

four 6 1/8-in. coaxial cables leading to the antennas. They have a total combined length of 6500 ft plus another 2000 ft on the ground from the transmitters to the tower. Further, the tower structure will incorporate ten intermediate inside platforms to provide rest and work areas for service and maintenance crews and one outside platform at the 650-ft level for special electrical equipment. At each platform level will be mounted signal lights, including nine 1000-w flashing beacons and 18 obstruction lights. Additional service facilities number full height access ladders and a two-man electric elevator running to the 1340-ft level.

All tower sections are hot dip galvanized and primed with paint after fabrication and before shipment. After erection, the tower will be painted orange and white (770 gal per coat) to conform with CAA regulations on such structures.

Extensive welding naturally was essential in prefabrication of the 200 odd leg members, each carrying two end flanges and one wing plate plus the 900 or so diagonals to which flat bolting plates were welded at each end. All welding was done manually, and it marked the first use by the Ideco tower shop of the Lincoln Electric Co.'s new Jetweld 1 electrode, in conjunction with 400-amp, a-c welding generators. This type of electrode provides physical properties equivalent to AWS E-7020 and has been designed for extra high-speed, deep-groove welding with a-c current. Because of its high deposition rate and easy slag removal, it produces weld metal at low cost per lineal foot in addition to having good wash-in properties and exceptionally little spatter or arc blow.

Jetweld is a coated electrode with a refractory coating containing a substantial percentage of powdered iron. This permits higher current settings and provides self-cleaning action making it ideal for cover pass work. Something over 11,000 lb of this rod was required on the complete tower job, giving an indication of the amount of weld metal laid down.

Flange joints on the heavier tower legs called for as many as 40 or 50 passes to build up the desired fillets inside and out. An illustration shows a setup for making these joints, the leg being turned mechanically to allow the operator to work in the downhand position. Using 3/16-in. rod at a current setting of 275 amp or 1/4-in. rod at 350 amp, it was possible easily to maintain a welding speed of 14–15 ipm. On the heavier flange joints of the counterbored type, as much as 40 lb of electrode went into a single joint. Flanges were flame cut from heavy plate or slab stock, some being up to 3 1/2 in. thick and requiring 1-in. fillet welds on the outside.

Briefly, the procedure for assembling a leg member was to place it in a jig and locate the flanges and wing plates for tack welding. This arrangement is indicated in one of the illustrations. The round leg section is held firmly by end plates on the jig with fixtures locating the plates at the exact 60-deg angle required. It was possible to tack weld the two flanges and fix wing plates in as little time as 11 min.

A crane then transferred the chain-held assembly to other jigs for completing the flange welds and for finishing the continuous 1/4-in. fillet welds on the wing plate joints. By turning the work in the jig through motor and chain drive all welding could be made downhand, this being necessary with the drag type Jetweld electrode. An example of a completed flange weld on a 7-in. round and 3 1/2-in. flange is illustrated to show the smooth, even texture and appearance of the Jetweld bead which required no special cleaning and is suggestive of welds made by the automatic hidden arc process.

A high rate of production was maintained on welding the bolting plates to the ends of diagonal bracing members with the aid of a special jig equipped with locating pins at either end over which the short bolting plates could be slipped. The round connecting member then was placed in slots flame cut into the plates, and the joint welded all the way around on both sides. Rigid spotting of the end plates compensated for any slight variation in length of the connecting round bar.

Repairing Castings from Coast to Coast

Experiences of a company specializing in the repair of cracked and broken cast iron

by W. H. Lane

MIDWEST Casting Repair, with headquarters in New Castle, Ind., specializes in the repair of cracked and broken cast iron. Our company endeavors to operate on 24-hr call to perform large repairs any place in the United States, Canada or Mexico. Although I have personally been in welding all my business life, our company has been specializing in this casting repair for the past 12 years. From a modest start with two welding operators, we now employ 15 operators.

A customer coming to us for a major repair job is like a person asking a surgeon for a major operation. In other words, our business has developed so that we are not called upon to perform any cast iron repair jobs of a minor nature. Our business has grown through word of mouth, repeat business and from welding shops that are not equipped or do not have the experience to perform complicated cast iron braze welding. Every job we do is on a contract basis and our guarantee on the work is, in general, equivalent to the guarantee of the manufacturer of the original part. To put it another way, if a manufacturer guarantees a part for a year, we will guarantee our repair job for the same period of time.

On receiving a call for a repair job, our operators take with them tool boxes which contain welding blowpipes, cutting attachments, hose, regulators, welding rod and pneumatic tools, including chipping hammers, air grinders and air hose. We have found that oxy-arc rod works very efficiently in some weld preparation and they are included in the tool boxes.

Prior to our arrival on a weld-brazing job, the customer has little to do in the line of preparation. In our work we require the minimum of dismantling of machinery to be welded. If the job requires scaffolding or special housekeeping around the area where welding is to take place it is expected that the customer will make these needed arrangements.

Before a torch is lighted, a great deal of consideration must be given to the over-all job and expecially to weld preparation. In my opinion, braze welding of the type

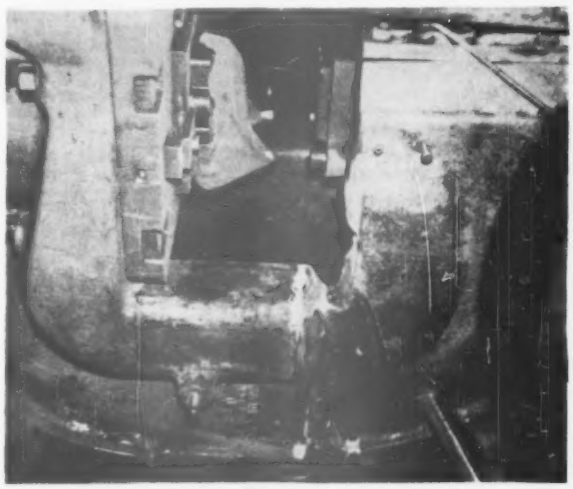

Figure 1

we perform is like building a house. If you do not have a good foundation you certainly cannot have a successfully built house and if preparation and planning is bad you end up with broken castings.

Our operators do not always follow the text book when it comes to welding preparation. For example, most people believe, and it is so written in many manuals, that a fairly deep V is correct for cast iron weld preparation. We have not found this to be so and I would like to explain very briefly what our technique is along this line.

It is also universal practice on cracks of certain types to begin welding at the end of the break and weld in the direction of where the break ends. We have not found it best to follow this practice and I would like to show you very briefly how we carry out the repairs on breaks of this type.

Our braze-welding methods in the matter of preheat are unusual. We disagree with the belief that the very nature of cast iron requires elaborate preheating prior to making repairs of cracks and breaks. Our long experience in braze welding cast iron using no preheat is convincing proof that preheat is not needed. We have performed literally hundreds of braze-welding repairs on cast iron. Preheating, as ordinarily thought of, has not been used in this work. By eliminating pre-

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Paper presented at the 1954 Annual Meeting of the International Acetylene Assn., Chicago, Ill., April 7-9, 1954.

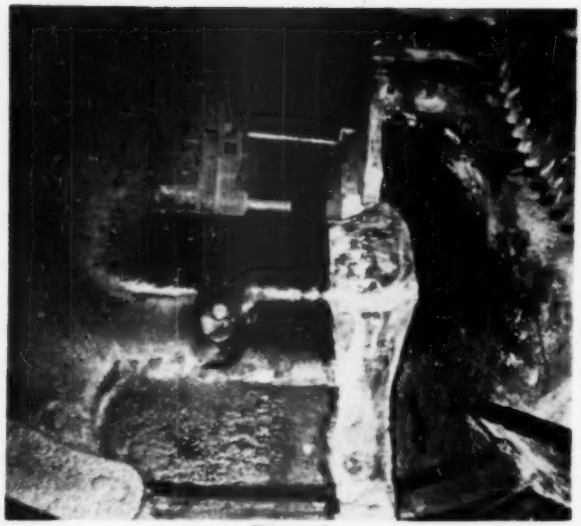


Figure 2

heating, it has been possible to avoid a great deal of dismantling, costly preheating ovens are not needed and, finally, the elimination of preheat reduces distortion that would require machining.

There are several factors that have helped us to eliminate preheating. First, we control stresses by proper welding procedure especially with respect to having as near perfect bond as possible. For example, our welders are trained to spend the necessary amount of time on each square inch of weld so that there is no possibility of a small spot not being properly bonded. Any such small spot in which the bond was missed might well mean a secondary crack in the base metal. Second, in braze welding we feel that it is necessary to break up long, straight stress lines. In addition to producing an irregular stress line, these extra bronze straps serve to reinforce the narrower bronze deposit.

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

In every welding job the bronze deposit is dressed down by grinding to original surface. This means that there is no reinforcing bronze metal on the completed job. In grinding off the excess, we remove a thin surface of bronze deposit which we feel is brittle and is apt to cause trouble in the future. During the actual welding, our operators only weld short distances that can be easily handled.

Our safety precautions are carried out as would be done in welding in temporary locations in industrial plants. By that, I mean we may require atmospheric gas test. Combustible materials must be removed. Fireproof screens to prevent sparks from reaching nearby locations are often required. Oil pools near jobs must be cleaned up and provision for fire extinguisher equipment should be made. Fire watchers are sometimes needed and required in especially hazardous locations.

Figure 8

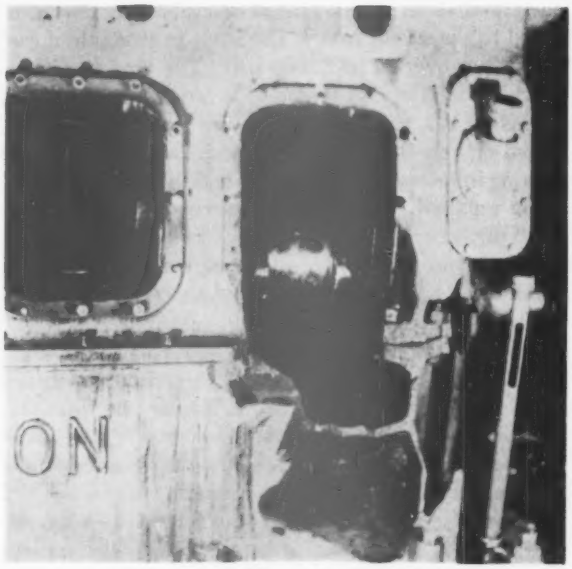


Figure 9

At this point, I would like to illustrate some of the types of braze welding of cast iron that we have performed in the last few years.

Shown in Fig. 1 is a cast-iron punch press frame which has been cut out with the oxy-arc ready for braze welding. You will notice that there has been a minimum of dismantling—even the dies are in the press. You will also note here our dished out weld preparation that is necessary for successful cast iron braze welding. The thickest part of the broken section is 8 in. and this tapers off to 5 in. at the back. It is about 30 in. wide and it required about 190 lb of bronze rod.

Figure 2 shows the welded frame as dressed down to original size. At this point, I would like to explain

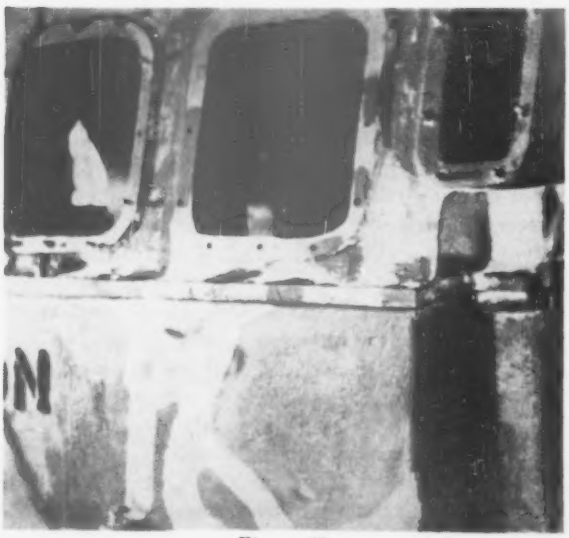


Figure 10

our practices on the amount of deposited metal as compared to the size of part. The average strength of cast iron is not over 20 to 25,000 psi. The bronze, after it has been molten and been set, is around 60,000 which means it has three times the strength of cast iron. Based on this it is possible to braze weld cast iron by putting in bronze equal to about one-third of the section being repaired. If we weld a piece of cast iron one-third of the way through we have as much strength as originally provided. This balance between deposited metal and the cast iron section is based on a close-to-perfect bond between bronze and cast iron. It is also based on a purposely enlarged area of bond. This equal metal strength practice is followed on the theory that cast iron does not have much give—no ductility. We have found that if we put in too much weld metal the part is likely to develop weaknesses at other points. We just put back the original strength.

Figure 3 is a metal shear base which was broken off. The thickest section shown here is 5 in. Oxy-arc was used in welding preparation and where possible it was prepared from both sides.

Figure 4 shows this shear following repair. Note in this picture the smoothly ground surface in which the bronze deposit is brought back to the original surface of the metal.

Shown in Fig. 5 are four rebuilt teeth out of nine that were broken on a half gear of a cotton compress. Each tooth required 180 lb of bronze. These teeth are about 5 in. in depth and 24 in. across. In welding preparation the base metal was chipped and ground out below the level of the tooth in order to get a firm base on the rim. You will note also that the rail has been cut out and all these teeth have been tied together and brought into one unit. The rail is acting as a support for the teeth. The bronze deposit on the side of the rail illustrates the desired stress line mentioned earlier.

The next three illustrations show the repair of a bearing pedestal of a steam engine. In Fig. 6 you see an air-driven grinder being used to prepare the edges to be braze welded. You might note that we get away from the usual V. The next illustration (Fig. 7) shows the welding under way, using about a No. 12 tip and bare bronze rod. The operator is making a small tack weld for the purpose of keeping the parts in alignment. After making this he starts welding at the region at the base of the picture and continues toward his tack weld knowing full well that it might pop loose as he proceeds. However, as he reaches the end of the juncture the area that has popped loose will, by contraction, be back tight again.

Figure 8 shows the completed braze weld in this steam engine. We have made many repairs to Diesel engines at oil pumping stations. In Fig. 9 you see an oil pump station Diesel engine base in which a broken connecting rod has fractured the crank case and block. The thickness of sections repaired ranged from 3 in. down to 1 in. This equipment was fixed in place. This is a little unusual because there are some sections that had to be repaired by having a welder inside one section of the

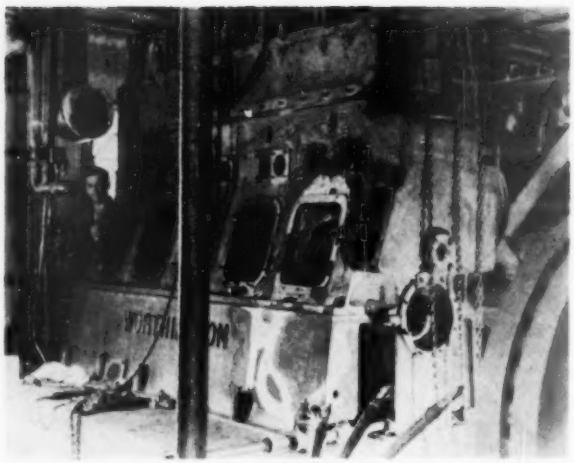


Figure 11

Figure 12

Figure 13

Figure 14

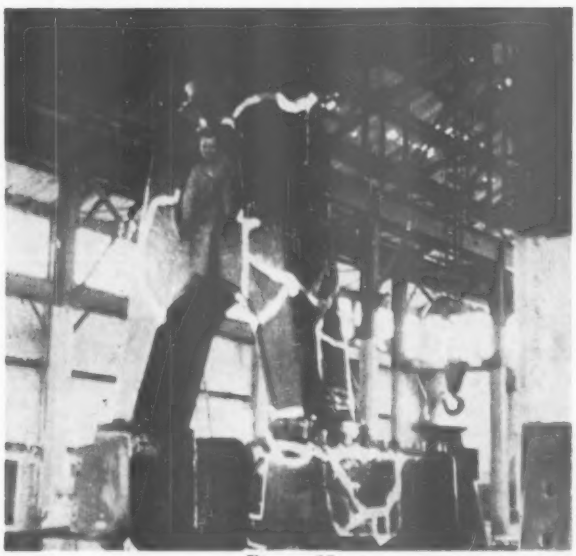


Figure 15

oil basin. Braze welding on pumping equipment is usually a "fire-alarm" job and every possible short-cut must be taken. The less dismantling the better and this fits in very well with our methods.

Figure 10 shows the completed section. Considerable braze welding was required on this part around the inspection hole. I would like to point out that none of this braze welding required any machine work even on the gasket surfaces.

Figure 11 shows an over-all view of this engine prior to reassembly. We perform lots of repair work in the nation's oil fields. Figure 12 shows a cast-iron sludge pump used in oil fields which had a break in each barrel. Operating pressure of this pump is 2200 lb. You will notice in this picture that each fracture has been cut out prior to welding and that the gasket flange is also ground down.

Figure 13 shows the pump just seen with completed weld at the cracks and also the "button-holing" around the gasket flange. This "button-holing" method is used in this type of equipment for two reasons. First, the extra bronze is welded on around the gasket flange *prior* to the repair of the cracks. This tends to hold in the cast iron at the cracked area due to the compressive action of the circular bronze deposit. Secondly, this "button-holing" eliminates the possibility of cracks that frequently develop on the sharp corners.

What you see in Fig. 14 is not a train wreck. It is a 1200-hp Diesel engine which had a broken crankshaft. This caused breaks in the cylinder, in the A-Frame and in the crankshaft base. From the looks of it, it hardly justified repairs but unfortunately replacement parts were not available and it was a very necessary piece of machinery at this location, which happened to be in Mexico. The sections to be braze welded varied from 1 to 3 in. in section and the job required 200 lineal feet of welding. Some new sections of steel plate were flame-fabricated, shaped with the blowpipe and welded in. On this particular job, we used generated acetylene. It took $2^1/_2$ months to complete the work, and in Fig. 15 you will see the section as welded. It was necessary during the welding to line up the cross-slide on the A-Frame to the other parts that had been broken. In order to make this alignment the parts were set up and checked with a surveyor's instrument located some distance away from the welding site.

Figure 16 is the completed job back in service. Approximately a ton of bronze rod was used. This job, in some respects, is one of the toughest we ever tackled. The mere problem of transportation into a remote section of Mexico to perform the work will be long remembered.

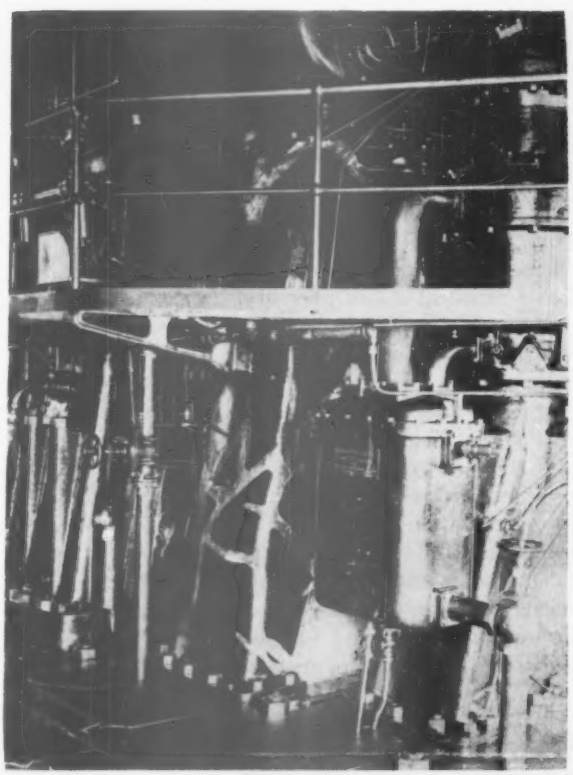


Figure 16

In conclusion I would like to say that oxy-acetylene braze welding has made it possible to perform hundreds of jobs for industrial customers everywhere in the United States. I can sincerely say that with respect to braze-weld failures we have never yet been called back to repeat on a job that we have completed. There are many important industrial companies, including the larger oil companies, that automatically call on us for repair jobs because they know that the cost of braze-welded repairs is going to be much lower than the cost of new equipment and the completed job will give just as good service as would a new part. I might also add that braze welding comes to the rescue in the repair of machinery for which replacement parts are not available.

Discussion of "Welding of 90/10 Copper-Nickel Alloy"

by Karl M. Weigert

IT HAD been observed by Messrs. Pease and Kihlgren that nickel-bearing copper-base alloy plates cracked under bending, while covered with molten solder. "Although some types of solder embrittle more than others," it was stated," all silver solders caused this effect."

The writer conducted some more experiments to find the cause of the "embrittlement" and possibly a solution to this problem.

Prior to the AWS meeting, experiments conducted on plates of about 0.02 to 0.03 in. indicated that alloys with cadmium, like the regular 45 and 50% alloys, did attack more rapidly than such alloys containing only silver, copper, zinc and nickel. An alloy containing 40% silver, 30% copper, 28% zinc and 2% nickel looked quite promising. After a practical demonstration with thicker plates and somewhat higher temperatures, Mr. Pease verified his own previous statements.

Returning from the convention the writer continued the investigations by testing various silver-copper compositions, ranging from 10 to 90% of silver. It was found that the high silver alloys showed the greatest "embrittling effect." On the other hand, copper-zinc alloys ranging from 30 to 50% of zinc did not crack up thick hard-rolled plates. Plates covered with a 50% brass, could be bent indefinitely, but in cooling, the solder itself started cracking on the surface. Photomicrographic studies did reveal that no brittle silver-nickel compounds were formed on the boundary line between the plate and the solder. However, it was apparent that the solder at temperatures about 1500° F did erode the plates considerably, leaving big undissolved chunks of plate metal near the solder. Thus this effect might be appropriately described as *"heat erosion and stress cracking."* That no brittle alloys or compounds are formed is also apparent from the fact that very strong and dependable joints are formed with silver solders, on this and stress-relieved parts.

After writing the above, the following reference came to the attention of the writer:

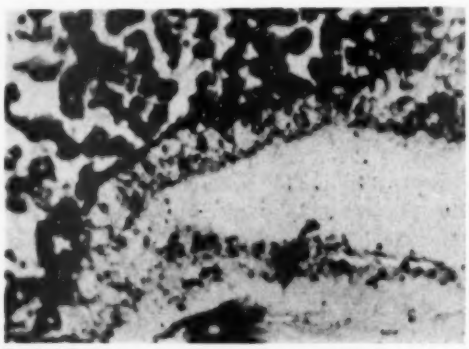


Figure 1

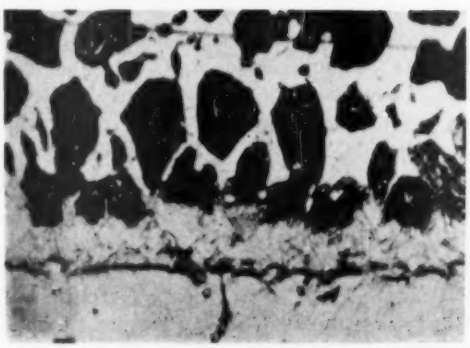


Figure 2

Karl M. Weigert is Research Metallurgist, Goldsmith Bros. Smelting & Refining Co., Chicago, Ill.

Paper by G. R. Pease and T. E. Kihlgren was published in the April issue of THE WELDING JOURNAL, 33 (4), 336-337 (1954).

In an article of R. S. Pelton, taken from *Materials & Processes* by James F. Young, 2nd ed., 1954, about brazing, it reads on page 825. "High nickel alloys such as Nichrome-resistant wires have a peculiar characteristic. In the fully annealed condition they braze very satisfactorily. But when under strain, silver should be kept away from them because the molten silver alloy will penetrate rapidly along the grain boundaries and sever the wire."

The nature of the effect is not yet quite understood. The penetration of the silver into the grain boundaries of the crystals is rather an observation than the description of the cause of the effect. Silver seems to have the ability to selectively dissolve copper and zinc rich phases leaving the nickel rich phases intact forming a raggedy eroded surface. By the inherent internal stresses and additional external strain a small crack progresses similar to a strained glass plate breaking after being cut by a diamond.

Author's Closure

The authors are happy to note that Dr. Weigert has confirmed their position with respect to the embrittling effect of molten silver solders on stressed specimens of various binary copper-nickel alloys. His observations that copper-zinc alloys are not embrittling under similar conditions is also in substantial agreement with data accumulated in this laboratory over a long period of time.

EDITORIAL PREVIEWS

Gar Wood Announces World's Largest Refuse Collection Bodies

THE world's largest enclosed garbage and rubbish collection truck bodies—three new, larger models of the Gar Wood Load-Packer—were announced recently by E. B. Hill, vice-president, sales, Gar Wood Industries, Wayne, Mich.

Three new models, two 20-yd and a 24-yd Load-Packer, will hold more garbage and rubbish than any other refuse collection body previously manufactured. They have been developed to provide cities with even more economical waste collection service than is provided with smaller units.

The new 24-yd Load-Packer will be able to serve 35% more households than the largest model previously available. In many cases, this will enable cities to reduce their refuse collection fleets by one-third.

Load-Packer garbage and rubbish collection truck bodies have revolutionized household waste collection throughout the United States, and in many foreign countries. They were originated and developed by Gar Wood in Detroit and have made Detroit the major manufacturing center for modern refuse collection bodies.

Bigger Load-Packers make possible more economical refuse collection because of both size and dual-thrust compaction of the load. A ram door and a jam-packing panel, both hydraulically operated, exert more than 100,000 lb of pressure in two powerful thrusts to provide compacted loads up to 200% bigger than with nonpacking truck bodies. These large loads reduce the number of trucks and crews needed for waste collection.

Larger Load-Packers are needed in many cities because of the disposal problem. As population increases, dumps and incinerators are being pushed further out from the center of the city. Longer hauls by trucks to dumps increase operating expenses and nonproductive collection labor and travel time. Larger capacities of the new Load-Packers will decrease such expenses to a minimum by decreasing the number of disposal trips.

Load-Packers provide not only more economical waste collection service but promote sanitation because the fully enclosed body contains odors and liquids and prevents unsanitary waste from blowing into streets, yards and alleys.

These modern waste collection bodies have saved cities millions of dollars in operating waste collection systems, since bigger loads because of compaction have reduced the amount of labor and trucks needed for waste collection and have necessitated fewer trips for

Figure 1

disposal. The new, larger Load-Packers will reduce these costs even more.

SOME WELDING DETAILS

1. These bodies are of all-welded construction, utilizing steel from 14 gage to $^1/_2$ in. thickness, exclusive of the hydraulic system.

2. The fabricated components are prepared by flame cutting, edge beveling, rolling and forming.

3. Welders of 200 to 400 amp are used, and electrodes from $^1/_8$ to $^1/_4$-in.

4. Grinding and cleaning tools used—disk grinders, rough wheels and slag hammers.

5. Fume exhausts, vacuum flux collectors and antispatter compounds are used in the welding procedure.

6. Approximate welding time involved in production is 90 man-hours per unit. About 20 welders are needed.

WRC BULLETIN NO. 19

The Welding Research Council has just issued Bulletin No. 19 of its Bulletin Series. This Bulletin is entitled, "Review of Welded Ship Failures" by Harold G. Acker, Shipbuilding Division, Bethlehem Steel Company. This report is one of a group prepared for the National Research Council's Committee on Ship Structural Design, to assist it in assessing the present state of knowledge of the motions and stresses in ships at sea, and the structural aspects of brittle fracture. The Committee on Ship Structural Design is advisory to the Ship Structures Committee.

Copies of this Bulletin may be ordered from the American Welding Society, 33 West 39th Street, New York 18, N. Y. Price $1.00.

New Welding Process Cuts Costs and Welding Times

HIGHER welding speeds, better quality welds, and lower operating costs are the main advantages of a new consumable-electrode, inert-gas arc-welding process developed by Westinghouse. It is claimed that field tests on the new process disclose a 15 to 20% faster welding speed at a 25 to 50% reduction in costs over other manual and semiautomatic inert gas methods.

Key to the new process, which uses ordinary welding grade argon to shield the arc, is a new coated wire—West-ing-arc MS-20 wire—a product of 5-year research and development. This wire produces best results when used with a newly designed welding gun, wire control and a new constant potential power source—the RCP, 500-amp, d-c arc welder. These new components (Fig. 1) considered separately or as a unit, offer many outstanding advantages in addition to increased speed at decreased cost.

The new process produces welds that can be painted without cleaning. There is virtually no spraying or spatter. Nor is there any slag-covering on the weld. The new process may be used on mild steels, with or without normal mill scale, on thicknesses from $^1/_{16}$-in. up. It can be used as either a semiautomatic process—where an operator holds the gun, or in automatic processes—where the gun is clamped into position and the work moved or where the wire is fed through an automatic head. Primarily intended for horizontal and flat position welding, the new process is not yet developed for vertical or overhead welding.

Fig. 1 The components of the new West-ing-arc process are all newly designed—wire, welder, gun and control

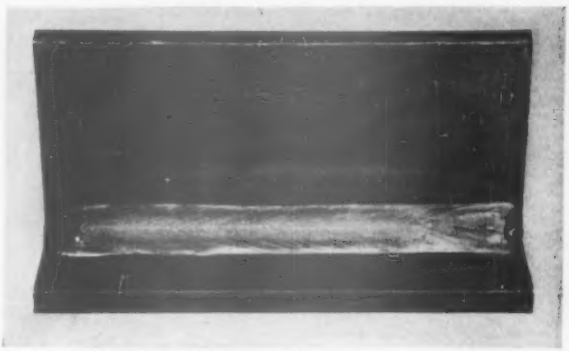


Fig. 2 This fillet weld shows the excellence in appearance of welds made with the new process

The new process, in contrast to most other processes of this type, uses straight polarity. The special coating on the MS-20 wire makes it possible to take advantage of some of the higher burn-off rates because it stabilizes the arc, eliminates spatter, and provides good penetration. The end result is a high quality weld at greatly increased speeds.

As can be seen in Fig. 2, weld appearance is excellent. Penetration is good (Fig. 3) and welds are of sound, X-ray quality.

Table 1 gives typical values of various physical properties at temperatures from 80° F to a −200° F. The excellent physical properties at low temperatures mean a weld low in contaminating oxygen and nitrogen.

Because of greater arc stability, this process uses about 33% less gas.

The electrode gun—rated at 500 amp—also incorporates many outstanding advantages (Figure 4). It is light in weight and exceptionally well balanced. This

Table 1—Physical Properties

Temperature, ° F →	*+80*	*0*	*−100*	*−200*
Yield point, psi	63,200	81,700	90,000	109,200
Tensile strength, psi	76,000	92,400	100,600	111,500
Elongation (% of 2 in.)	27.9	25.85	25.50	27.13
Reduction in area, %	69.4	69.90	61.30	57.90
Impact* West-ing-arc, ft-lb	100.0	80.0	22.0	...
Impact* E-6020 manual, ft.-lb	58	25	21.0	...

* V-notch Charpy impact test.

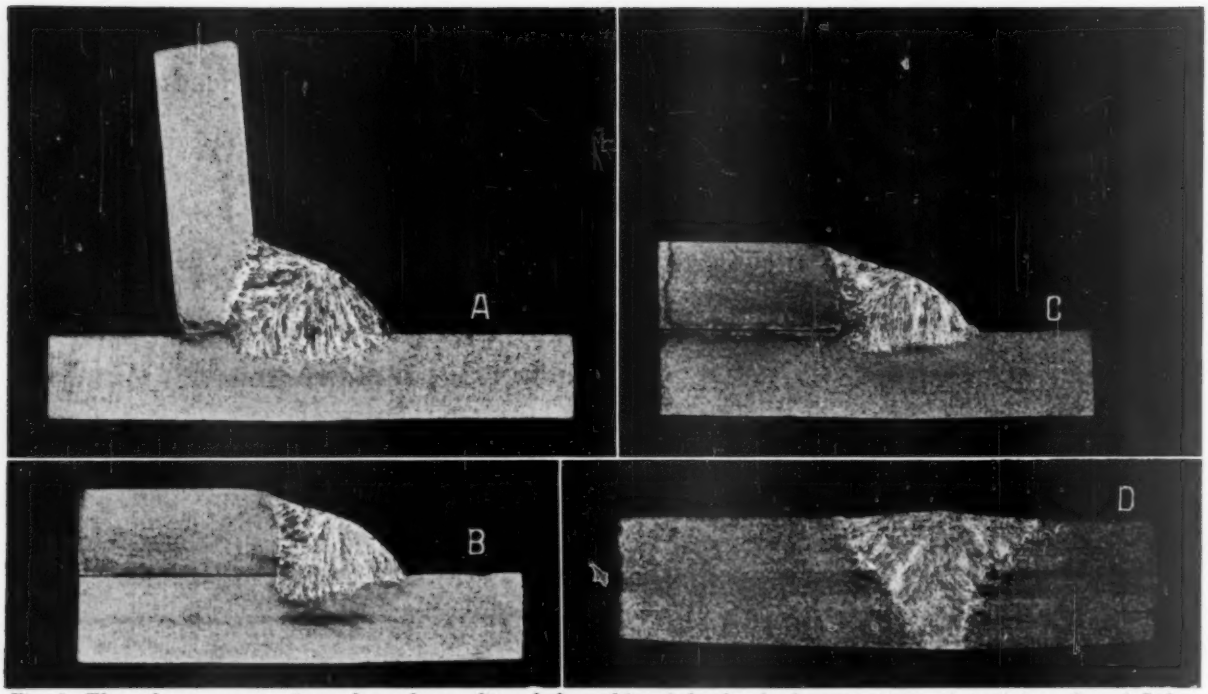


Fig. 3 These four cross sections show the quality of the weld and the depth of penetration. A, tee joint; B and C, lap joints and D, butt joint

means that operators can weld for long periods without fatigue. No tubing is exposed on the gun, which delivers wire, power, gas and water. The tip of the gun is specially designed for high water-cooling efficiency, meaning longer life.

The control for feeding the wire (Fig. 5) has been designed to supply wire at a constant preselected speed under all loads. Both of the drive rolls are driven through a $^1/_{12}$-hp d-c gear motor. The electrode length beyond the tip of the gun is controlled on stopping so that neither wire nor operator time is wasted by trimming. Designed for portability, the control panel is light weight and operates from a conventional 110-v, a-c supply. An adjustable water pressure switch prevents operation of the unit when the water pressure is below a predetermined limit. Since maintenance is a key factor, all the control components are long-life devices and are made readily accessible by means of a swing-out panel.

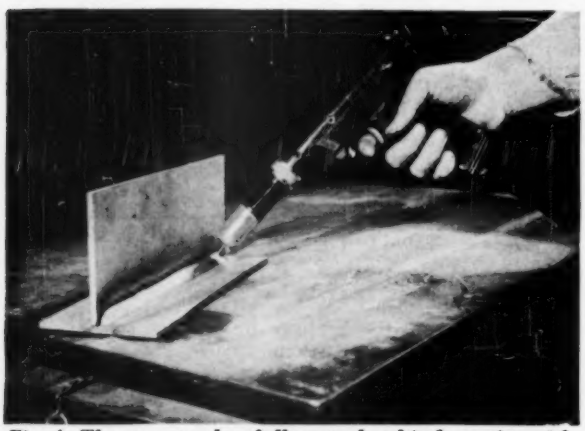
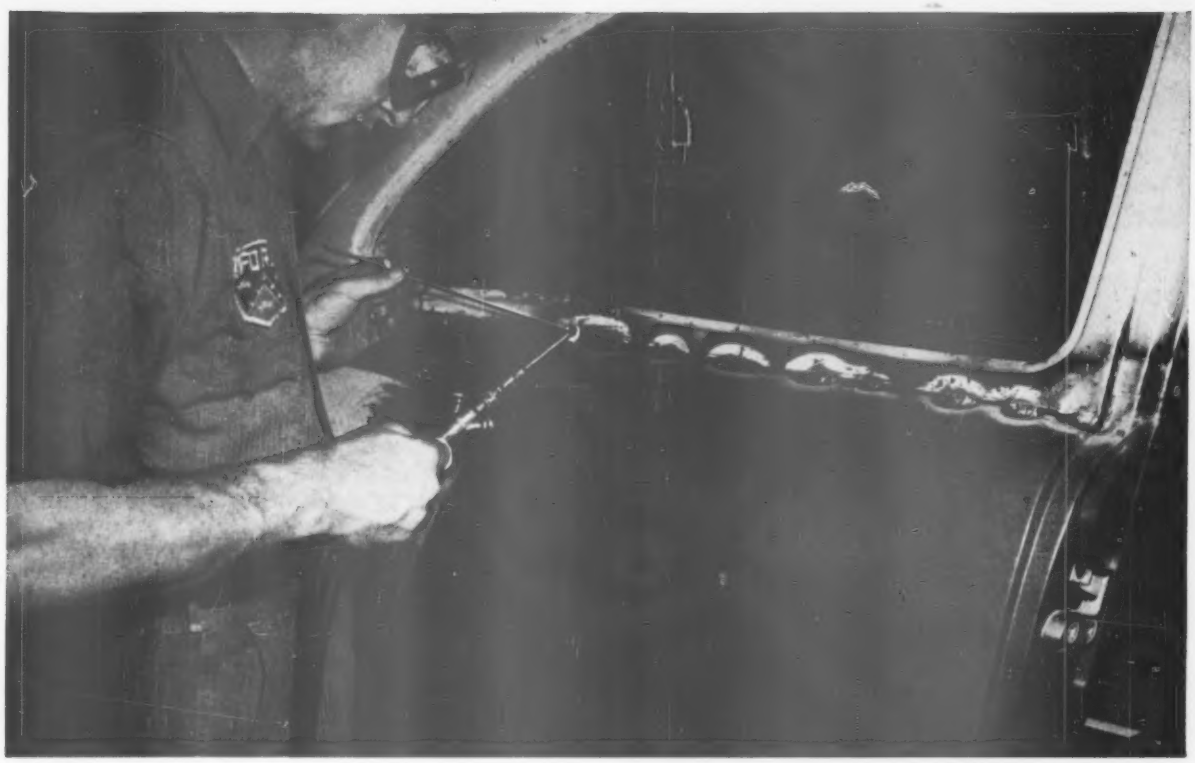


Fig. 4 The operator has full control at his fingertips with this wire gun. All necessary controls are incorporated into this well-balanced unit

Fig. 5 The control is portable and feeds wire to the gun at a constant rate. It is built so that it will require a minimum of maintenance



Back on the Road

Oxy-acetylene and air acetylene equipment produce quality auto repairs

by J. A. Fluharty

AUTOMOBILE repairmen are now performing a great number of jobs with oxy-acetylene and air-acetylene equipment. These in-shop repairing and rebuilding operations are saving time and money for shop owners and customers.

Cutting operations on all thicknesses of metals are fast and clean when done with an oxy-acetylene cutting blowpipe. Welded joints are strong and can be finished to a fine appearance. Operations which do not require high temperatures, such as soldering and tinning, are done quickly and easily with the air-acetylene torch.

J. A. Fluharty is with the Linde Air Products Co., San Francisco, Calif.

The air-acetylene torch is widely used in the automobile repair shop to fill body dents with solder. By following this procedure, the job is accomplished easily.

The first step is to straighten the dents as much as possible. Then clean the surface with a wire brush. Next, paint the affected area with muriatic acid, and heat with the air-acetylene torch. Repeat the acid painting and flow on stick solder. Heat the solder to a pasty condition and smooth it over the dent. The dent is now filled and the repaired area is ready for finishing and repainting.

Although the most frequent automotive application of the air-acetylene torch is in body work, its usefulness does not end when the dents are filled. Air-acety-

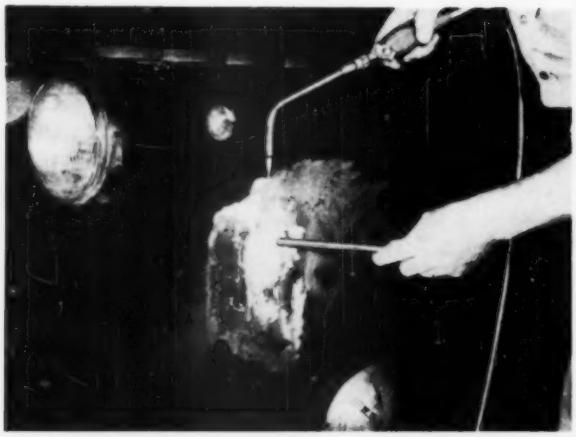


Fig. 1 The damaged area of this fender has been cleaned and treated with muriatic acid. When a full deposit of body solder has been made, smoothing and repainting will complete the job

lene equipment is used to repair leaks in the cooling system, and lubrication lines, and to solder the wire connections in the electrical system. Shatterproof glass can be cut to shape, and the plastic layer melted with a paint burner, forming new windows quickly, easily and cheaply.

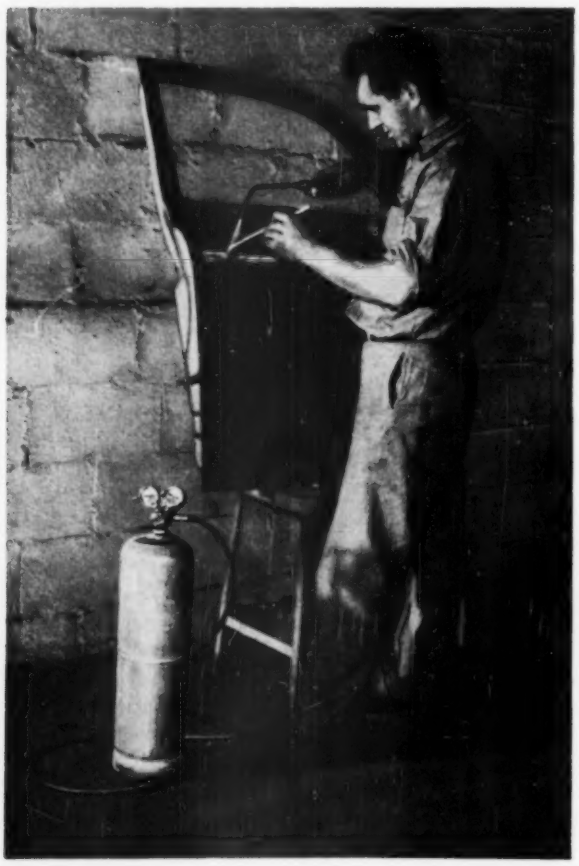


Fig. 2 Small dents are quickly filled with body solder. The air-acetylene torch supplies heat where it is needed to produce a quality repair

Fig. 3 Making shatterproof windows is an easy task. Cut both sides of the glass with an ordinary glass cutter, and melt the plastic layer with a paint burner

OXY-ACETYLENE—THE HEAVY-DUTY FLAME

For heavier operations, the oxy-acetylene flame has proved useful again and again to the body man. Damaged body sections can be removed quickly when the repairman uses a cutting attachment. The operator is able to weld new sections in place simply by substituting a welding head for the cutting attachment. Bent frame members can be restored to original shape by heating with the oxy-acetyleme flame and reforming them. The oxy-acetylene flame is practically a blacksmith's forge in the auto repair shop.

Fig. 4 Here an oxy-acetylene blowpipe with a cutting attachment is used to remove a damaged section from a door. The cutting flame will slice through any steel part of an automobile

Fig. 5 By removing the cutting attachment, shown in Fig. 4, and replacing the welding head, the operator is able to repair cracks in the door lining, or weld entire new sections into place

Fig. 6 After this damaged section is cut away, the bent frame will be heated with an oxy-acetylene flame. Through use of the hydraulic jack, the heated frame member will be straightened

The automotive uses of oxy-acetylene equipment are not confined to body work. Rebuilding or repairing jobs on the engine or other component parts of an automobile can be done with a blowpipe. Cracks in castings, such as cylinder blocks or gear housings, are quickly repaired by braze welding, in this manner:

First vee the crack, and clean the area to be welded with a wire brush. The area should be heated until the break turns a dull red. At this moment, melt on bronze rod so that it tins on the surface and sides of the break. Add rod metal until the weld is built up slightly higher than the surface of the casting. Be certain that the added weld metal fuses with the previously deposited bronze rod.

OTHER OXY-ACETYLENE JOBS

Worn battery terminals are rebuilt by melting lead welding rod into a mold placed over the terminals. Gear teeth, worn by many years of service, or broken due to neglect or accident, are rebuilt with bronze welding rod.

The oxy-acetylene flame is also used to hard face parts which may be subjected to unusual wear. Hard facing can be performed on the wearing portions of gears, contact points on valves and valve seats, and

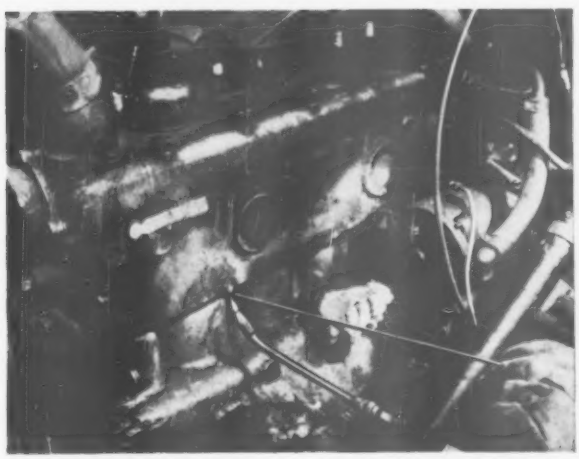


Fig. 7 Braze welding of castings is done quickly and easily. Here, a crack in the cylinder head is repaired without removing the part from the engine

Fig. 8 To build up worn battery terminals, a mold is fitted over the terminal and new lead fused to the worn part. The form and amount of the build-up is controlled by the mold

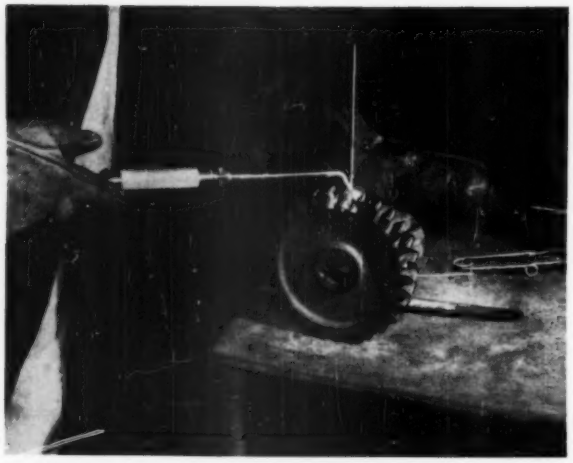


Fig. 9 The operator is rebuilding a broken gear tooth with bronze welding rod. Through this rebuilding process many parts are restored to useful service, instead of being scrapped

Fig. 10 This truck engine valve is being rotated during the hard-facing operation. Truck owners who hard face wearing surfaces estimate that the valves last from 2 to 4 times as long as unprotected ones

door hinge pins and latches, adding years of service to these parts.

COMMON SENSE INSURES SAFETY

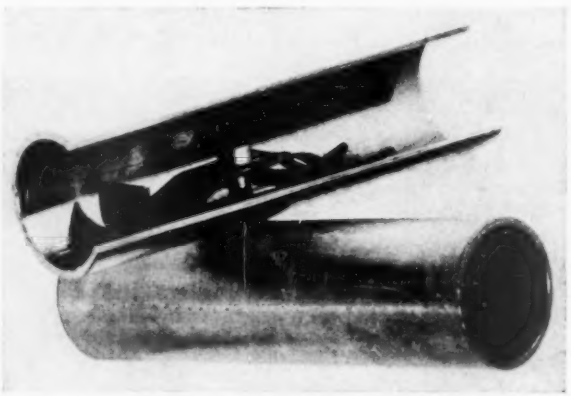
Automobile repairmen throughout the world are using oxy-acetylene or air-acetylene equipment in complete safety. The largest safety factor in using blowpipes is the common sense of the operator. The automobile shop is an ideal place for the "Hose warts" and "Fire-Starting Imps" to find a home. Flammable liquids are present in the auto shop all the time. All cars, especially older models, may have coats of grease on various parts of the chassis and frame, as well as at the lubrication points of the vehicle. By following recognized rules of safety and using his head, the auto repairman can look forward to safe, sure, cost-cutting operations with a blowpipe.

Tubular Furniture

FASTENING two metal tubes together, particularly in the manufacture of the increasingly popular tubular metal furniture, is easier, less expensive, and more satisfactory through an application of stud welding which is covered by a patent issued recently.

Tubes fastened by the newly patented method can be disassembled quickly, and one tube can be pivoted relative to the other while still connected. The new patent (U. S. Patent Office No. 2,686,687) was issued to the Nelson Stud Welding Division of Gregory Industries, Inc., manufacturer and distributor of the Nelson stud welding equipment which annually saves industry millions of dollars and man-hours.

In the application covered by the new patent, a special headed stud is first end welded to a tube, which may be of any cross-sectional shape, not necessarily circular. The stud is passed through a hole formed in one side of the other tube. The clip, with a slot in one end forming two spring legs, is inserted in the second tube until the spring legs straddle the stud, below the head. Spring tension holds the clip firmly against the



This cutaway section shows how the legs of tubular metal chairs and tables are fastened together by an end-welded stud and ingenious spring clip covered in a patent just issued to the Nelson Stud Welding Division of Gregory Industries, Inc.

The special headed stud is first welded to the outside of one tube with a Nelson stud welding gun. The stud is then passed through a hole in one side of the upper tube and the slotted spring clip is inserted so that the spring tension holds the clip firmly against the stud head and against the walls of the second tube. The tubing used for the legs in folding chairs may be pivoted freely, as shown by this view.

stud head and also against the walls of the second tube. The clip may be removed by pressing it down and pulling it from the tube by grasping the flange on one end.

Although primarily intended for fastening two tubular members, the procedure also may be used advantageously for securing two flat plates.

Various other stud welding applications in tubular furniture simplify assembly, eliminate most hand welding, drilling and through-bolting, and frequently improve appearance through the absence of protruding bolt heads. Among the other metal furniture applications are these:

1. Curved tubular legs are secured to table tops by studs end welded to the underside of the table, then passed through holes formed in the tubing and secured with wing nuts.

2. Four small tubes are assembled around a larger tube to form a four-legged pedestal for a table. Studs end welded to the smaller tubes are passed through holes in the large tube and fastened with nuts inside the large tube.

3. Tubular corner table legs, to which a threaded stud is welded, are assembled to table aprons by passing the stud through a hole in a special corner bracket which fits into slots in the aprons. A nut holds the bracket on the stud.

4. Special studs welded on the front of the leg sections of tubular chairs prevent the chairs from tipping forward.

Hydraulic Press Repaired by Braze Welding

By C. F. Redding

A BROKEN hydraulic press can be costly in many ways to a pulp mill. Aside from the cost of a new press, the time that the equipment is out of action is lost time to the mill. But, braze welding helped one mill to keep this cost to a minimum.

When a cast-iron hydraulic press cracked due to a defective foundation, it was decided to repair the break by braze welding. First, both sides of the crack were veed and cleaned. The broken portion was bolted to the press, and the area around the break was preheated. Using a welding blowpipe with a large head, the operator carefully braze welded the 2-in. thick section back to the main press body.

Braze welding this break in a hydraulic press saved the mill approximately $1000, besides the time that would have been involved in obtaining a new press. The repaired press was back on the job quickly, operating at full capacity.

C. F. Redding is connected with the Linde Air Products Co., Pittsburgh, Pa.

Fig. 1 Before the broken portion of this hydraulic press was braze welded, it was veed and cleaned. Then, it was bolted to the press and the area around the break was preheated

Fig. 2 After the part was preheated, an operator carefully braze welded the break. Braze welding this press saved approximately $1000 for the operators of a pulp mill

the AMERICAN WELDING SOCIETY

activities • related events

A Swan Song

In 1922 after having experimented with a one-issue magazine, a monthly printed news letter, the use of a trade magazine as its official organ and separate preprints of Annual Meeting papers, the three-year-old AMERICAN WELDING SOCIETY decided to launch a monthly magazine which later was to be named THE WELDING JOURNAL. Although small in size (6 x 9 in.) and consisting of 44 pages, a circulation of 1000 copies and with practically no financial backing, I was nevertheless quite proud that the Board of Directors had selected me as its Editor. Before the end of the first year I had also acquired the additional titles of Business Manager and Advertising Manager.

The SOCIETY and the JOURNAL grew up together. Nine years later the JOURNAL size was changed to the standard size (approximately 9 x 12 in.) In 1935 a Research Supplement was added and in 1948 a Practical Welder and Designer Section. These are merely cited as recognized milestones. Actually the JOURNAL has continuously increased in size and stature and every attempt has been made to improve format and contents, and to make it generally useful to the members of the SOCIETY and Industry in keeping with the finances, scope and objectives of the SOCIETY.

After 33 years at the helm as its Editor, the time has come to say au revoir. This is the last issue of THE WELDING JOURNAL to bear my name as Editor although I will stand by a few months longer, until May 1st, as "Consulting Editor." Naturally, I have taken this step with considerable regret but I will be sixty in May, 1955 and the time has come to ease up a bit and to concentrate my energies to the growing Welding Research Council. This step has, however, been made easier by the knowledge that a younger, energetic and highly qualified individual—"one of my boys," in fact—B. E. Rossi is to become the new Editor.

To the hundreds of authors, public relations executives, officers of the SOCIETY, the advertisers, the paid staff, members of the JOURNAL COMMITTEE (past and present) and to the members of the SOCIETY who have helped me in my job—many thanks! Public acknowledgment of indebtedness and thanks are also hereby made to my able assistant through the years—Miss C. M. O'Leary.

W. SPRAGUE, *Editor*

Introducing the New Editor

B. E. Rossi

Back in 1940 it was my good fortune to become acquainted with B. E. Rossi or, stated more accurately, with his work. The McGraw-Hill Publishing Co. received the manuscript for a new book *Welding and Its Application* and asked me to review it, which I did. Apparently my endorsement was sufficient to lead the McGraw-Hill Co. to go ahead with its publication. It was a very successful venture as was also the companion book prepared by the same author, B. E. Rossi, entitled *Manual of Instructions in Welding and Cutting.*

My next contact with Mr. Rossi occurred some seven years later—December 1947—when I served as a member of a small committee that selected B. E. Rossi to become Executive Secretary of the Pressure Vessel Research Committee of the Welding Research Council. His pleasing

B. E. Rossi

personality and his ability to write and edit made a favorable impression on all who came in contact with him and some four years later I asked Boniface how he would like to understudy me as Editor of THE WELDING JOURNAL on a part-time basis. We were all pleased when arrangements were consummated to the satisfaction of all committees concerned whereby Bonney devoted one day a week starting in October 1951 as Assistant Editor of THE WELDING JOURNAL. In October 1953 Bonney also became Secretary of the Technical Papers Committee of the SOCIETY.

In 1936, Mr. Rossi received a degree of Mechanical Engineer from Stevens Institute of Technology, Hoboken, N. J., having attended this college on a full four-year scholarship from Hoboken High School. In 1938, he attended a special course in Welding Engineering given by Dr. Wendell F. Hess at Rensselaer Polytechnic Institute. While at Stevens, he was active in extracurriculum activities, and as a result of his efforts on the "Stute" and "Link," school publications, was elected to Pi Delta Epsilon, the National Collegiate Honorary Society for Journalism.

As to some of his background experience, from 1936 to 1939 Mr. Rossi was associated with L. O. Koven & Brother, Inc., of Jersey City, N. J., Engineers and Metal Fabricators. He did a considerable amount of work in the field of welding, including basic research, and was responsible for quality control of weldments of all types. Also, as Industrial Engineer, he was charged with the proper functioning of the wage incentive system for the entire plant, including time studies, job analysis, and rate setting. He was assistant to the Shop Superintendent and to the Production Manager; and, in addition he did work in safety engineering and personnel relations. In line with the latter, he founded and directed, on his own initiative, the "Koveneer," a plant publication.

One of the early jobs that attracted the welding industry's attention to Mr. Rossi was that of Director of the Welding Division of the Delehanty Institute of New York City. He organized this Division and was in full charge of all teaching and business activities until 1943. He selected the staff, and supervised the work of graduate engineers, welding technicians, shop assistants and office personnel. He prepared and wrote all courses in welding engineering and shop practice; lectured in welding engineering; and designed all school equipment.

From May 1943 to December 1946, Bonney was employed by the Columbia Aircraft Corporation of Valley Stream, N. Y., prime contractors to the U. S. Navy. He was in charge of the Materials, Processes, and Standards Section of the Engineering Department. He was technical adviser on selection of materials and standard parts to be used in the design and construction of airplanes and on the processing of these materials, such as welding, machining, riveting, heat treating, anodizing, plating and finishing.

Prior to joining the Welding Research Council, Bonney was employed by the Bloomfield Works of the General Electric Co., in charge of the Welding Section of the Technical Services Department.

Mr. Rossi holds a Professional Engineer's License and, for the past ten years has done consultant work for a number of engineering, manufacturing and educational organizations. Some five years ago, he initiated a series of lectures in Welding Engineering at the Industries Training School of Stevens Institute of Technology. These original lectures have constituted the first course of this type ever given at the Institute.

Mr. Rossi is a member of the following professional societies: AMERICAN WELDING SOCIETY; American Society of Mechanical Engineers; American Society for Metals; Institute of the Aeronautical Sciences; American Society for Engineering Education; and the National Society of Professional Engineers.

Mr. Rossi has found time to author a new McGraw-Hill book entitled *Welding Engineering* which promises to surpass in sales his first book.

THE WELDING JOURNAL is in good hands! You will begin to see the imprint of the new Editor with the next issue. With the help of the Members of the SOCIETY and others involved, THE WELDING JOURNAL has a bright future indeed!

W. SPRAGUE, *Editor*

Memorial Resolutions

(Approved by Board of Directors, AWS)

Dr. Wendell F. Hess

It is with the most profound sorrow that the AMERICAN WELDING SOCIETY records the untimely death on Apr. 21, 1954, of Wendell Frederick Hess, whose life for twenty-five years had been devoted to the advancement of science in the field of welding, and to the activities of the SOCIETY and the welding industry. Dr. Hess recognized the need for more scientific knowledge of welding in 1928 before he had finished his academic education. He became inspired by the opportunity for research, development and teaching in this field and proceeded to devote his life to the work for which he became distinguished throughout the technical world.

He served the SOCIETY as an officer at every level, starting with his local section in 1934 and his regional district in 1938, and assuming the responsibilities of a directorship in 1944 and the presidency in 1945. He was made an honorary member in 1948. In recognition of his contributions toward the advancement of the science of welding and the development of the welding industry he was awarded the Lincoln Gold Medal in 1944 and the Samuel Wylie Miller Memorial Medal in 1949. He was further honored with the opportunity of giving the Adams Lecture at the annual meeting of the SOCIETY in 1946.

His friendly nature, his deep understanding, and his willing cooperation endeared him to his many friends and associates. His farsighted vision and his determination overcame many difficult obstacles and made possible his success in the work to which he was devoted.

Resolved, That this expression of sorrow in the loss of our associate, beloved by those who knew him and recognized by all as an outstanding scientist and engineer, be entered in the Proceedings of the AMERICAL WELDING SOCIETY and that a copy be sent to the immediate family of Wendell Frederick Hess, with

We sincerely appreciate the valued support, assistance, and guidance of all AWS members and the welding and allied industry throughout the year and extend our hearty wishes that you may enjoy a very

merry christmas

and a

happy new year

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A. O. Smith's BIG THREE lets you job-match your electrodes . . . helps you pick the one that's exactly right for your particular operation.

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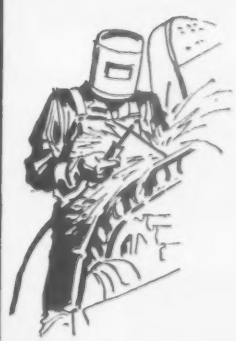
SW-12 This is a "hot" E-6012 . . . versatile, smooth and fast. Designed for applications where the upper end of the amperage range is employed. Weld deposition is much faster than with SW-11. Welder can hold a close arc without sticking. SW-12 also works well where fit-up is poor . . . bridges across, assures a good weld and won't penetrate through.



SW-17 A "hot" E-6012, can take from 30-40 more amperes than others. A general purpose high rutile type electrode for heavy production welding, where fit-up is poor and high ductility and mechanical properties are desired. Built-in toughness is one outstanding characteristic. Deposition is extremely fast, physicals are excellent. It is highly recommended for horizontal single pass fillet work.

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an expression of our most sincere sympathy in their loss.

Casin W. Obert

Resolved, That the AMERICAN WELDING SOCIETY records with profound sorrow the passing on Apr. 16, 1954, of its member and colleague, Casin W. Obert, who for more than forty years devoted himself wholeheartedly to the advancement of the welding industry and the SOCIETY.

During his long and eventful career his friendliness, always willing cooperation, and understanding nature endeared him to his many friends and associates. His complete absorption in his work and determined nature overcame many difficult obstacles and made possible outstanding achievements in the field of welding.

His boundless enthusiasm and devoted perseverance in research on the welding of boilers and other pressure vessels led to the establishment of welding rules for boiler construction. He was a member of the Editorial Committee for all three editions of the AMERICAN WELDING SOCIETY'S WELDING HANDBOOK and served notably on many other SOCIETY committees. In recognition of his four decades of creative contributions to the art and science of welding, he was awarded the Samuel Wylie Miller Memorial Medal at the 1951 Annual Meeting of the AMERICAN WELDING SOCIETY.

Resolved: That the AMERICAN WELDING SOCIETY acknowledges the loss of an old and dear friend and associate, and expresses its sincere sympathy to the family of Casin W. Obert.

G. T. Van Alstyne

The AMERICAN WELDING SOCIETY at a meeting of its Board of Directors held in Buffalo, N. Y., on Thursday, May 6, 1954, unanimously adopted the following resolution:

Resolved, that the AMERICAN WELDING SOCIETY records with profound sorrow the untimely death on Apr. 21, 1954, of Gansevoort T. Van Alstyne, a member and colleague who contributed so much to the promotion and advancement of the welding industry during a period of more than 30 years.

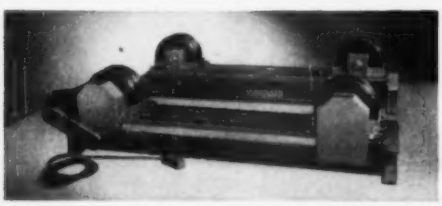
If words are to touch upon something of what Van was to those who knew him well, they should suggest not only the earnestness of purpose he brought to his work, but his sense of humor in his relationships with people.

He had qualities which earned for him sincere respect as an authority in advertising—his chosen field, and he communicated to those who worked with him a sense of the fun that goes with living in the midst of all its problems and obstacles.

There was, then, a quality of happiness—a wisdom—about Van that came from a grasp of life's deepest values. He will long be remembered.

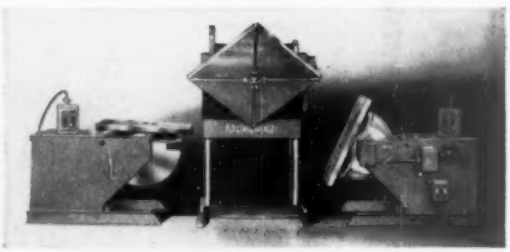
Resolved, that the AMERICAN WELDING SOCIETY acknowledges the very great loss of a rare and fine associate and expresses its sincere sympathy to the family and many friends and colleagues of Gansevoort T. Van Alstyne.

Aronson QUALITY POSITIONING EQUIPMENT



PRECISION BUILT GEAR DRIVEN POSITIONERS with Magnetic Brakes
500 lbs. to 24,000 lbs. capacity

HEAVY-DUTY PRECISION BUILT RUBBER TIRED TURNING ROLLS
5,000 lbs. to 150 tons capacity



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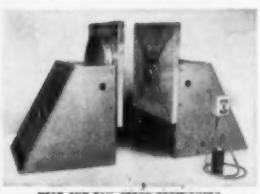

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NEWS OF THE INDUSTRY

Western Metal Congress

"The New in Metals and Metal Working" will stand as the theme of the Ninth Western Metal Exposition and Congress, Mar. 28 through Apr. 1, 1955, in Los Angeles.

William H. Eisenman, Secretary, American Society for Metals, says the display will occupy 150,000 sq ft at Pan-Pacific Auditorium, largest of Los Angeles' exposition structures. The Congress will be in the Los Angeles Ambassador Hotel.

Both events, Mr. Eisenman announces, will feature metals, metal-working equipment, processing, techniques and tooling. The Exposition is being set up to accommodate more than 50,000 engineers, plant heads and department directors.

Last year the Western Metal Exposition under Mr. Eisenman's management, drew more than that number. The coming display will be entirely on one floor level in the auditorium and two large pavilions connected to the permanent structure.

Both the Exposition and Congress are known and established for having been on the Coast eight previous times since 1929. Nineteen technical societies are cooperating with ASM in sponsorship.

Particularly, the show and technical sessions will disclose new developments in building better products faster and at less outlay.

Members of 20 cooperating societies will be registered free for the show by showing their membership cards. In addition, invitations granting a no-charge registration or entrance will be distributed by the exhibitors. Audiences at the Congress in Ambassador Hotel need merely walk inside and take seats for any session.

International Institute of Welding Meeting

The annual meeting of the International Institute of Welding will be held in Zurich, Switzerland, Sept. 11 to 17, 1955. In connection with these meetings there will be a public session at the Federal Institute of Technology, Zurich, September 16th. The subject of this public session will be "Welding in the Construction of Hydroelectric Generating Stations" (penstocks, turbines, sluice-gates, locks, etc.)

The Swiss delegation is looking for suitable authors who would be willing to prepare unpublished papers on interesting work in this field. Each country will be allowed not more than four papers.

Papers may be presented in French, English or German, but must be accompanied by a synopsis in the other two languages. Illustrative photographs and drawings should be prepared in such a way as to be readily made into blocks for printing. In view of the short time available during the Public Session, only a limited number of papers can be chosen for final presentation. The selection will be made by an editorial committee of Swiss experts in the fields concerned.

It is not proposed to read the papers during the Public Session, but simply to discuss them. The papers will be printed prior to the Congress and sent to all those attending so that they can prepare the discussion.

Anyone desiring to prepare a paper on this subject should communicate at once with W. Spraragen, Secretary, American Council of the IIW, 29 W. 39th St., New York 18, N. Y. The United States must notify the Swiss delegation by Jan. 31, 1955, of the papers that will be presented.

The manuscripts themselves are to be sent (in duplicate) *by Mar. 15, 1955*, to: Comité d'organisation IIS/IIW, Réunion annuelle 1955 à Zurich, Case postale, *Bâle 6*, Suisse, where they will be forwarded to the editorial committee.

Square D Expansion

Square D Co. has acquired the property and facilities of the Iowa National Manufacturing Co., of Cedar Rapids as a wholly owned subsidiary, it was announced recently by F. W. Magin, President of Square D. As a part of the transaction, Square D will take over a 26-acre site on Lincoln Highway in the city's southwest section and complete a 112,000-sq-ft manufacturing plant presently under construction by Iowa National.

Operations in Cedar Rapids will comprise an important phase of Square D's general expansion program, according to Mr. Magin, and will supplement manufacturing factilities in the company's seven U. S. plants and in Mexico City and Toronto. A major producer of electrical distribution and control equipment for home and industry, Square D recently announced plans for a new plant to be built in Secaucus, N. J., and revealed a program to invest $2,500,000 in the current fiscal year in capital expansion, twice the amount expended the previous 12 months for new facilities and buildings.

Harnischfeger Office

A new district office in Cleveland, Ohio, has recently been opened by the Welding Division of the Harnischfeger Corp., whose home office is at Milwaukee, Wis. The address of the new office is Harnischfeger Corp., Cleveland Welder Sales, 1821 NBC Building, 815 Superior Ave., N. E., Cleveland 14, Ohio.

A. T. Mortrud

The new Cleveland office is under the District Managership of A. T. Mortrud and it will handle sales of all P&H welders, electrodes, positioners, and accessories, as well as provide assistance with various welding problems.

Research Laboratories Directory

The National Academy of Sciences National Research Council is now compiling the tenth edition of *Industrial Research Laboratories of the United States*, a directory of American industries and businesses which maintain scientific research and development facilities.

The directory will include nongovernmental laboratories devoted to industrial research. *Research* for the purposes of this directory includes industrial development work on processes and products, as well as fundamental and applied research. Laboratories engaged primarily in routine testing and control but carrying on research activities as well will also be listed in the directory.

The directory will indicate the type of ownership or sponsorship of the laboratory

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(that is, whether it is company-owned, an independent commercial laboratory, a trade association laboratory or a nonprofit foundation or institute). It will also indicate the kind of research activity performed and the nature of the services offered, such as research only for the parent organization, research on a fee or contract basis, consultation and advice, and testing and analysis.

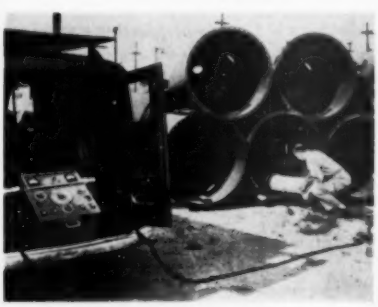
The number of professionally trained members and technical personnel of the scientific research staff will be shown, as well as the number of additional employees.

Industry purchases a large percentage of each edition; scientific and technical societies use it in their studies; and government agencies often refer to it when awarding contracts for research and development.

Publication is scheduled for mid-1955. There is no charge for listing in the directory. The book is a nonprofit undertaking; the price will be determined by the cost of publication. Industrial laboratories that may wish to be included in the directory but have not received a questionnaire may receive one by writing to James F. Mauk, Staff Associate, National Academy of Sciences-National Research Council, 2101 Constitution Ave., N. W., Washington 25, D. C.

New Portable X-Ray Unit

A new type of portable industrial X-ray unit, capable of producing a 360-deg radiation sweep, which enables radiographers to attain new highs in inspection efficiency, and to greatly reduce the cost of inspection, has been announced by the General Electric Co., X-Ray Department, Milwaukee, Wis.



Many products can be set up in a circle around the "business head" of the machine and all can be X-rayed with a single exposure. This can reduce radiographic operation time in some industries by as much as 97%! If desired, the unit can also operate as a conventional type with a limited angle cone of radiation.

The unit can be placed inside a pipe or pressure vessel and used to take "inside out" X-ray views. The advantage of this technique is that it confines the radiation within an enclosed area and this increases protection to personnel against radiation exposure, and also that it permits the making of a complete circumferential weld radiograph with a single exposure.

Known by the model number OX-175, the new machine consists of a tank to house the X-ray tube (and energizing transformers) linked to control and power source by interconnecting cables. The tube head weighs less than 185 lb, has a diameter of only $10^1/_2$ in. and a length of only 42 in. The small control, measuring only 18 by 18 by 14 in., weighs 145 lb.

The OX-175 can be mounted and used in field, shop and laboratory in many different ways: On a mobile truck with elevating tube stand, rotating tube stand or tube carrier; on a bridge crane; installed inside a radiographic cabinet; on a mobile base; or on a fixed mounting with an elevating tube stand.

The entire unit can be easily transported to any location desired. It can be operated at X-ray tube voltages from 45,000 to 175,000, contains many features for the operator's convenience and automatic safeguards against improper operation.

Bridge Awards

Ten bridges in ten states from a field of 68 entries were selected as the most beautiful steel bridges in the country opened to traffic in 1953, in the American Institute of Steel Construction's 26th Annual Aesthetic Bridge Competition. Stainless steel plaques will go to the three top winners. Honorable Mention Certificates will be awarded to the remaining seven.

The winner of Class III, for bridges with fixed spans under 400 ft and costing less than $500,000 was Robert Street Underpass (Pedestrian), over South Freeway, Fort Worth, Tex. The bridge was designed and plans prepared by the bridge design group of the Texas Highway Department, under the immediate supervision of A. M. Gordon, Supervising Designing Engineer. The General contractor was J. M. Purvis of Fort Worth with Joe Hook as Construction Superintendent. Fabricator was the North Texas Steel Co., Inc., Fort Worth, Tex. J.T. McNair was Supervising Construction Engineer for the Highway Department, with Justin M. Bingham as Project Engineer. This bridge was selected "because it has a fine, graceful profile and because as a pedestrian bridge, it is designed in an intimate scale to fit into the community it serves."

Welding was used extensively in building the bridge. The superstructure consists of a concrete deck carried by two continuous steel beams of 44-75-44-ft spans. The beam sections over the interior bents were built-up, all-welded girders consisting of two $^3/_8$- x $8^1/_8$-in. flange plates and a $^3/_8$-in. web plate of variable depth.

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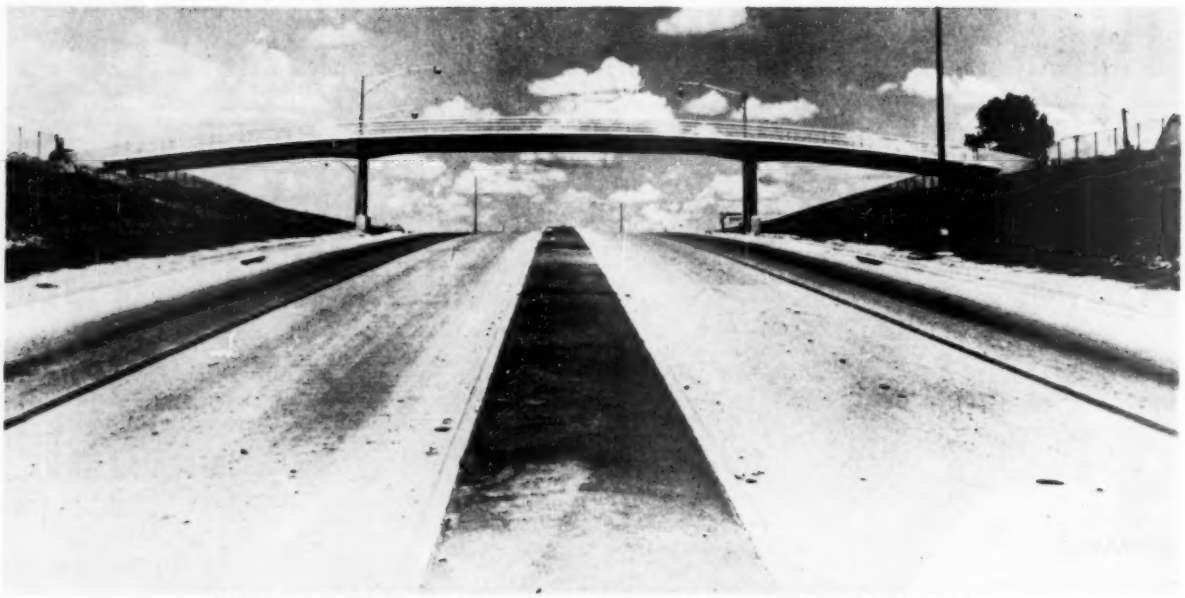


Robert Street Underpass (Pedestrian), Over South Freeway, Fort Worth, Texas

By this means the girder was increased to a maximum depth of 32 in. at the bents to resist the heavier negative moments, without serious encroachment on the clearance required over the freeway lanes. Twenty-one inch WF beams, of 62 and 68 lb, were found to provide ample sections to resist positive moments.

A continuous parabolic vertical curve was obtained in the deck by cambering the WF beams as much as possible and raising the floor slab above the beam tops with haunches where required.

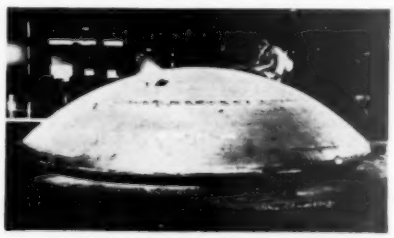
The bridge carries a residential street sidewalk 8-ft wide over the South Freeway. Most of the traffic served consists of elementary school children attending a public school located one block east. The railing was designed to harmonize with that used on adjacent vehicular bridges over the Freeway but was faced with chain-link wire fabric to prevent children falling or crawling through it.

The two interior bents and three sections of the superstructure were completely assembled in the shop of the North Texas Steel Co., and hauled to the site on two trucks. All of the steel was erected in about two hours, using a truck-mounted crane, except for the permanent welding of four girder splices. Traffic on the two heavily traveled freeway lanes was detoured over the adjacent frontage streets for less than one hour while the center section of the steel span was lifted into place and secured by temporary bolted clamps. The remaining construction was carried on without interfering with traffic using the freeway.

The contract cost of the bridge was $11,117.38, which was financed with 100% State funds.

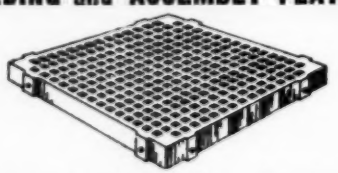
Biggest Heads Ever Spun

These biggest heads ever spun are going to be used just once—to test penstocks for the Littleton, N. H., hydroelectric development of the Connecticut River Power Co. Measuring 21 ft, 8 1/2 in. in diameter, four of these giants of 1 1/4-in. steel were spun on Lukens Steel Co.'s 276-in. flanging machine in Coatesville, Pa., for the Walsh Holyoke Fabricators Division of Continental Copper & Steel Industries, Inc.,



Holyoke, Mass. Because of their size, they posed a shipping problem. This was overcome by flame cutting them in half after they were completed, and shipping them in two pieces by flatcar to Holyoke, where they were reassembled.

WELDING and ASSEMBLY PLATENS



Floor plates — bending tables — layout tables — straightening tables — dog blocks — bending blocks — blacksmith blocks. 5'x5' — 6'x6' — 6'x8' — 6'x10' — 5'x10' — 6'x12' — 3'x3' — either 6" or 7" thick.

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94 Washington St., Brookline Village 46, Mass.

Buy "PROVEN FLUXES"
Years of GUARANTEED SATISFACTION
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"ANTI-BORAX" FLUXES
Insist on them—Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
No. 4 Braz-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By
ANTI-BORAX COMPOUND CO., INC.
Fort Wayne, Ind.

NEW LITERATURE

Silver Brazing

Handy & Harman Co., 82 Fulton St., New York 38, N. Y., in their brochure "Low Temperature Brazing News" No. 66, describe some interesting recent silver brazing applications. Copy available on request.

Nickel Alloy Cast Irons

Bulletin A-115, consisting of 16 pages, 13 charts and 11 tables, tells how to increase the usefulness of cast irons and improve the properties by alloying and heat treatment. For easy understanding a glossary of terms is included. International Nickel Co., Inc., New York 5, N. Y.

Resistance Welding

Sciaky Bros., Inc., 4915 W. 67th St., Chicago 38, Ill. has published a new 8-page bulletin, No. 317-2 SP2 and EP2, covering all phases of the new standard commercial SP2 and EP2 series air-operated, press type, low-impedance single-phase spot and projection welders.

Ductile Iron

Bulletin DI-15, consists of 12 pages with 30 illustrations charts and tables on composition, machinability and mechanical properties as cast and as heat treated. It reviews the development of this relatively new family of irons which possesses the process advantages of cast iron and which has engineering properties that approach those of cast steel. Comparisons show its advantages over gray iron, malleable iron, cast steel and forgings and an evaluation of its impact on industry is given. International Nickel Co., Inc., New York 5, N. Y.

WRC Bulletin No. 19

The Welding Research Council has just issued Bulletin No. 19 of its Bulletin Series. This Bulletin is entitled *Review of Welded Ship Failures* and is written by Harold G. Acker, Shipbuilding Division, Bethlehem Steel Co. This report is one of a group prepared for the National Research Council's Committee on Ship Structural Design, to assist it in assessing the present state of knowledge of the motions and stresses in ships at sea, and the structural aspects of brittle fracture. The Committee on Ship Structural Design is advisory to the Ship Structures Committee.

Copies of this Bulletin may be ordered from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Price $1.00.

Properties of Cast Monel

A new technical booklet describing the engineering properties of cast Monel has just been issued by the Development and Research Division of the International Nickel Co., Inc.

Cast Monel combines high strength with good ductility and corrosion resistance. The material has a tensile strength comparable to carbon steel and gives good performance under conditions of abrasion and erosion. Like wrought Monel, cast Monel is a nickel-copper alloy containing about two-thirds nickel.

The booklet is available without charge through the Technical Service Section of Inco's Development and Research Division, 67 Wall St., New York 5, N. Y.

Resistance Welding Bulletin

Sciaky Bros., Inc., 4915 W. 67th Street, Chicago, Ill., has recently issued Vol. 4, No. 1, *Resistance Welding at Work*, covering several case histories of Sciaky single-phase, electric-resistance welding equipment as used at Configured Tube Products, Chicago, Ill., fabricators of gas-stove burner assemblies; Metal Auto Parts Co., Indianapolis, Ind., manufacturers of automobile radiators; and Berns Manufacturing Co., Chicago, Ill., manufacturers of the Berns Air King Fan.

To receive these interesting techniques of small, single-phase welding applications, write direct to the Chicago plant for copies of *Resistance Welding at Work*.

Hard Surfaced Loads

Coast Metals, Inc., Little Ferry, N. J., has issued a new folder describing the chemical and physical properties of Coast Metals No. 18 which we furnish either in the form of hard-surfacing weld rods, or in cast form, made to the customer's specifications.

The alloy is the same whether it is designated as No. 18, which is a bare rod for gas welding; No. 118, which is a coated rod for arc welding; or in cast form. Primarily made for steam valve seat trim, it has been proved in actual service for many years, and has produced excellent results in many other applications, resisting wear caused by heat combined with abrasion or impact, steam erosion, and many types of corrosion.

Ampco Welding News

Ampco Metal, Inc., has released the Third Quarter issue of its publication, *Ampco Welding News*.

Articles in this issue explain how knife holders on wood chipper machines used in the papermaking industry were strengthened and gave longer wear and how service life was increased for dredging boom sheaves through welded overlays. There are also articles on the successful welding of malleable iron parts and how to increase the life of automobile molding dies.

Other stories feature the fabrication of agitators to resist corrosion and abrasion, common misconceptions of resistance welding electrodes and remarks and photographs of the German Welding Exposition at Essen, Germany, in June 1954.

Free copies of this interesting issue can be obtained by writing Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Plastics Engineering Handbook

Plastics Engineering Handbook of the Society of the Plastic Industry, Inc. Price $15. 813 pages including a comprehensive index of 21 pages. Published by Reinhold Publishing Corporation, 430 Park Avenue, New York 22, N.Y.

This is a completely re-written and expanded edition of the SPI Handbook which made its appearance some seven years ago. It is one of the most complete compilation of engineering knowledge available on the design, materials and processing of plastics products.

Chapter 17 of this Handbook is devoted to the cementing, welding and assembly of plastics. A special fold-out adhesives chart is included in this section, and constitutes a very exhaustive tabulation of the types and characteristics of adhesives used to join plastics to each other or to other materials.

Q. Is it possible to be certain we are using the right filler metal for consumable electrode welding?

A. Yes. Alcoa's new I.G.* Electrode is available in such a wide range of alloys and sizes that there is a right one for every job.

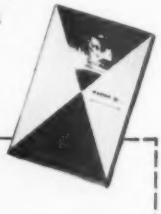
Every production lot of Alcoa® I.G. Electrode is test welded and the welds X-rayed for soundness. Each 10-lb spool is individually packed to maintain the super-smooth finish to assure soundness of weld and smoothness of feed. Each of three alloys, 1100, 4043 and 5154 (formerly 2S, 43S and A54S), is available in six diameters. There is no better electrode.

*inert gas

ALCOA ALUMINUM

ALUMINUM COMPANY OF AMERICA

A new, 176-page text, *Welding Alcoa Aluminum*, has just been released by Alcoa. It covers every phase of welding in complete detail. For a free copy, fill in and mail the coupon.



ALUMINUM COMPANY OF AMERICA
930-M Alcoa Bldg.
Pittsburgh 19, Pa.

Gentlemen: Please send book, *Welding Alcoa Aluminum*.

Name _____

Company _____

Title _____

Address _____ City _____ State _____

Q. Where is Alcoa's new I.G. Electrode available?

A. Contact your nearest Alcoa sales office, or, for immediate delivery, call one of the Alcoa Distributors listed below. He carries a complete range of alloys and sizes, and you'll find him well qualified to work with your welding experts.

ALBANY, N. Y.
†Eastern Brace-Mueller-Huntley, Inc.

ATLANTA, GA.
†J. M. Tull Metal & Supply Co., Inc.

BALTIMORE, MD.
Whitehead Metal Products Co., Inc.

BIRMINGHAM, ALA.
†Hinkle Supply Co.

BOISE, IDAHO
Pacific Metal Co.

BUFFALO, N. Y.
Brace-Mueller-Huntley, Inc.
Whitehead Metal Products Co., Inc.

CAMBRIDGE, MASS.
Whitehead Metal Products Co., Inc.

CHARLOTTE, N. C.
Edgcomb Steel Co.

CHICAGO, ILL.
†Central Steel & Wire Company
†Steel Sales Corporation
Corey Steel Co.

CINCINNATI, OHIO
Williams & Co., Inc.

CLEVELAND, OHIO
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SYRACUSE, N. Y.
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Whitehead Metal Products Co., Inc.

TAMPA, FLA.
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TOLEDO, OHIO
Williams & Co., Inc.

TULSA, OKLA.
Metal Goods Corp.

YORK, PA.
Edgcomb Steel Co.

*Home Office

PERSONNEL

Armstrong Heads Interpretive Report Committee

T. N. Armstrong, a member of the International Nickel Co.'s Development and Research Division in New York, has been named Chairman of the newly formed Committee on Interpretive Reports of the Welding Research Council.

The new committee will consider the field of welding research and closely allied fields and will have interpretive reports prepared on subjects of current interest in these fields. The reports are not intended as literature surveys but rather as summaries of the present knowledge in a concise, easily understandable form.

Prepared by an outstanding authority selected by the committee, the reports will be issued about three times a year.

Jessen Promoted

Nicholas C. Jessen has been named Assistant Superintendent of the Barberton, Ohio, works of the Babcock & Wilcox Co.'s Boiler Division, according to an announcement made recently by G. J. Hartnett, Jr., Superintendent of the plant.

Mr. Jessen received his education in Europe and the United States and joined Babcock & Wilcox in 1930 at the Bayonne, N. J., works. He was transferred to the Barberton plant in 1932, where he has served in the capacity of Chemist, Metallurgist, Welding Engineer and Assistant Director of the Works Laboratory.

During the past two years Mr. Jessen has had two assignments in Europe where he observed heavy forging practice, steel production, welding and boiler fabrication methods. He holds a professional engineer's license and taught metallurgy in the evening classes at the University of Akron for four years. He is a member of the American Society for Metals, the AMERICAN WELDING SOCIETY and the American Society of Mechanical Engineers. He has been active in ASME Boiler Code work, devoting much time to the Committee on Welding.

Nicholas C. Jessen

W. L. Lutes Promoted

William L. Lutes has been appointed Manager of the Hard Surfacing Department of the Electrode Division of the McKay Co., Pittsburgh, Pa., it was announced by Fred A. Kaufman, General Manager. Mr. Lutes will be in charge of development and application research of hard-surfacing electrodes in the York, Pa., plant of the company.

Mr. Lutes has broad experience in the field of welding, having served progressively as Welding Engineer for Cooper-Bessemer and Technical Service Representative and Metallurgical Engineer with the McKay Co. since 1950. He is a member of the American Society for Metals and the AMERICAN WELDING SOCIETY, and is a representative of the AWS-ASTM Committee for Filler Metal.

Inco Promotes Haller

C. T. Haller, Jr., has been appointed in charge of the Pittsburgh, Pennsylvania, Technical Field Section of the Development and Research Division of The International Nickel Company, Inc., it was announced by Donald J. Reese, Assistant Manager of the division.

Mr. Haller whose appointment became effective November 1, 1954, succeeds William H. Sparr, Jr., who has been transferred to New York and appointed in charge of the Steel Section of the company's Nickel Sales Department.

A metallurgist, Mr. Haller joined International Nickel in January, 1945, as a member of the Pittsburgh Technical Field Section. He was appointed in charge of the Cincinnati, Ohio, Technical Field Section in 1951.

A Master of Science graduate of the Carnegie Institute of Technology, Mr. Haller before joining Inco was with the Carnegie Illinois Steel Corporation, Pittsburgh; Latrobe Electric Steel Company, Latrobe, Pa., and the Metals Research Laboratory of the Carnegie Institute of Technology as a metallurgist. He is a member of the AMERICAN WELDING SOCIETY.

NEW PRODUCTS

Forged Dock Hose Connectors

Oil companies and barge lines prefer that flanged hose connectors be made of aluminum, since it is light in weight, corrosion resistant and has nonsparking characteristics. However, the conventional connector is cast and its brittleness often causes it to fail under the hard treatment given it by modern steel loading facilities. Fortunately Tube Turns, Louisville, Ky., a division of the National Cylinder Gas Co., has come up with two types of forged connectors. They are many times more ductile than their troublesome cast counterparts, and will stand the daily gaff.

Dock hose equipped with Tube Turns' forged aluminum connectors can be furnished by the various rubber companies in this field. Tube-Turns' flanged fittings of forged aluminum, for making branch connections and abrupt changes in direction, are supplied through Tube Turns' distributors.

Several major oil companies have already switched from conventional cast connectors to connectors made up of forged Tube-Turns' flanges and fittings, and others are preparing to follow suit.

Cutting Torches

Universal Cutting & Welding Equipment Manufacturing Co., Inc., 2850 Ravenswood Rd., Fort Lauderdale, Fla., announces two new torches. At the present time they are manufacturing and marketing the Rigger "H" torch, for propane cutting, and the Rigger "A" torch for cutting with acetylene, propane and natural gas.

Service of these torches, if not available locally, can be obtained at the factory at minimum rates. Catalogs and price sheets are available on request.

All-Purpose Electrode

The Sureweld "CE," a new all-purpose electrode for welding mild steel has been announced by National Cylinder Gas Co., Chicago.

According to NCG, field tests have shown the new electrode to have high operator appeal because it is very easy to handle in all positions over a wide current range, and forms a slag that is exceptionally easy to remove. It gives a high rate of deposit with little spatter, resulting in beads of uniform appearance and fine even ripple, flat to slightly convex in profile.

"CE" is classed as an AWS E-6010 electrode but exceeds specifications for this class in physical properties. Tensile strength of deposited metal, for example, is 75,000–85,000 psi. It conforms to specifications of the principal codes for welding boilers and pressure vessels.

The new electrode is available in seven sizes from $^3/_{32}$ to $^5/_{16}$ in. in diameter, in 12-, 14- and 18-in. lengths.

Mang-Trode

A new covered manganese bronze electrode for high-speed metal-arc welding of manganese bronze and yellow brass castings and sheet and plate has been announced by the Weldrod Department of Ampco Metal, Inc., Milwaukee, Wis. The trade name of this new product has been designated as "Mang-Trode."

These electrodes operate at relatively high current densities on reverse (positive) polarity, direct current for fast deposition. Arc action is smooth and spatter losses are very low.

Mang-Trode can be applied at room temperature without the excessive preheat and interpass temperatures required by other methods. Deposit composition, mechanical properties and color match those of manganese bronze.

Available through Ampco Weldrod Distributors, Mang-Trode is offered in $^1/_8$-, $^5/_{32}$-, $^3/_{16}$- and $^1/_4$-in. diam sizes in standard cartons of 50 lb each.

Welders' Goggle

The problem of obtaining greater ventilation in a welding goggle without permitting penetration of light has been solved in the Penoptic Model 500 welders' goggle manufactured by the Pennsylvania Optical Co. Air passages in the side shields admit an indirect flow of air to the inner cup area but are ingeniously placed and angled to prevent light penetration. Additional ventilation through wide channels between the lens retaining rings and cupwalls provides a direct flow of air to the inner lens surface. The Penoptic Model 500 also features metal reinforcing rings molded into the inner rim of the cup to insure retainment of original cup thread dimensions under all conditions. Lens-retaining rings are of aluminum, anodized to resist corrosion and threaded to allow easy lens replacement without tools. Brown opaque thermoplastic goggle is equipped with standard 50-mm size welding lenses and cover glass. Also available with heat-treated welding lenses and plastic cover glass.

Improved Automatic Wire

An improved line of automatic wire with size tolerances held to $^1/_{1000}$ of an inch has been announced by the Mir-O-Col Alloy Co., Inc., of Los Angeles, Calif.

A notable feature of the new Mir-O-Col wire is its firmness. After accurate measures of specific alloys are placed into the wire it is then scientifically compressed, packing the alloys firmly in place. The wire will not crush and actually feeds like a solid wire.

Annealed and layer wound in 100-lb coils, Mir-O-Col automatic wire is ideal for use where a large number of similar parts are to be rebuilt or where considerable material is to be applied to a single part. All Mir-O-Col automatic wire can be operated on a-c or d-c current, with the submerged arc as well as other automatic welding methods.

Literature describing the improved automatic wire is available upon request to Mir-O-Col Alloy Co., Inc., 312 N. Avenue 21, Los Angeles 31, Calif.

Hard-Facing Alloy

A new chrome-cobalt-tungsten hard-facing alloy for general hard-facing applications where wear and corrosion resistance are required has been announced by Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich.

The new alloy, called Walloy No. 6, is available as hard-facing rod for oxy-acetylene torch application. It has been developed to provide a material that is ideally suited to such applications as edger rolls, swaging mandrels, engine exhaust valves and seats, hot-casting stripper bits and such hot-work tools as punches, dies, shear knives and blades. The major advantage in the hot-work applications is the material's ability to hold a good cutting edge.

Walloy No. 6 provides high impact, corrosion and abrasion resistance. It resists oxidation, does not readily heat-check under pressure at elevated temperatures, and is virtually unaffected either by most common corrosive chemicals or by atmospheric corrosion. It also resists chipping

Here is a steel with 90,000 psi. yield strength that you can weld or flame-cut easily

USS Carilloy T-1 Steel

gives you 100% joint efficiency without pre- or post-heating... provides amazing sub-zero toughness as well as high temperature strength

Now, with USS Carilloy T-1 Steel, you can flame-cut or weld very high strength parts either in the shop or the field *without* the need for heat treating equipment. In addition to its great strength, this new quenched and tempered alloy steel has unusual resistance to impact abrasion.

The secret to the excellent weldability of T-1 Steel—and its durability under high impact stresses—is its amazing toughness even at temperatures far below zero. In field tests of non-stress relieved, *welded* pressure vessels, T-1 Plate Steel withstood impact wallops of 2,000,000 ft. lbs. at temperatures as low as 38° F. below zero. Steels customarily used for pressure vessels—even if stress relieved—could not take that kind of punishment. But the T-1 Steel and every weld in the vessels remained sound. The welds, made by manual arc welding with E 12015 low hydrogen coated electrodes, developed the full strength of the parent metal. No special techniques were used.

How this new steel cuts fabricating costs

T-1 Steel cuts costs in several ways. You can reduce the thickness and weight of heavily stressed parts by taking advantage in design of its very high yield strength of 90,000 psi. Thinner sections mean less welding time, less welding rod required.

You can make these welds without the lost time and extra expense of pre- or post-heating. And with no need for heat treating equipment you can fabricate or make repairs either in the shop or the field—wherever it is more convenient and less costly.

You can often take advantage of T-1's high strength to build larger size pressure vessels and storage tanks. As a result, you can build *one* vessel big enough to replace *several* of present design. Or you can build the *same* storage capacity with less steel, less welding, less cost.

Where to use T-1

Carilloy T-1 Steel is now being used to cut costs, increase service life, reduce size and weight of pressure vessels, power shovels, mining cars, and rotating machines. It is being considered seriously for use in high pressure pipe, bridges, and penstocks. It is applicable to a wide range of tough jobs where the stress is primarily tensile, where great toughness or high temperature strength is needed—in fact, everywhere that you want a very strong steel that can be welded easily.

Write for complete information. United States Steel, Room 4578, 525 William Penn Place, Pittsburgh 30, Pa.

UNITED STATES STEEL CORPORATION, PITTSBURGH • COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO
TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA. • UNITED STATES STEEL SUPPLY DIVISION, WAREHOUSE DISTRIBUTORS
UNITED STATES STEEL EXPORT COMPANY, NEW YORK

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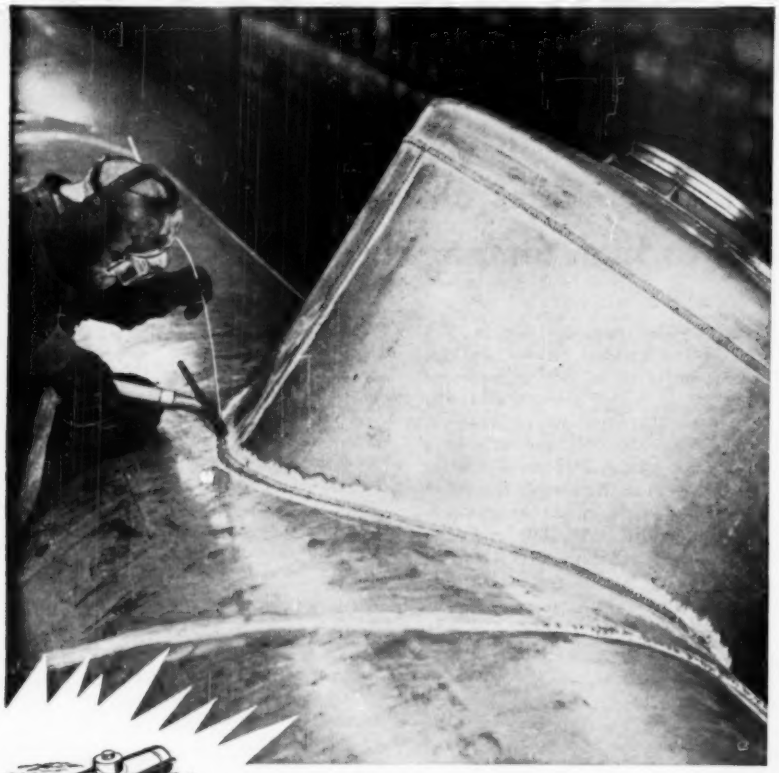
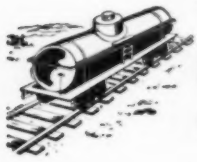
ELECTRIC FURNACE OR OPEN HEARTH

COMPLETE PRODUCTION FACILITIES IN CHICAGO OR PITTSBURGH

UNITED STATES STEEL

ARCOS FOR FINEST QUALITY WELDS





*Putting profitable benefits into welded **aluminum** tank cars*

Besides permitting bigger pay loads with less "dead" weight, aluminum performs a dual role on this *welded* tank car. Inside, it provides even distribution of heat from heater coils to keep viscous fluids free-flowing for fast unloading. Outside it eliminates maintenance—never rusts, never needs painting.

An important key to success on *any* aluminum welding job is the quality of weld metal. Newly-developed ARCOS ALUMINUM RODS and ELECTRODES assure you a dependable answer to this requirement. They give you the properties you need to make the most from aluminum's durability, strength, appearance and maintenance-free qualities. Specify Arcos for profitable aluminum welding. Arcos Corporation, 1500 South 50th Street, Philadelphia 43, Pa.

WELD WITH ARCOS

ALUMINUM RODS AND ELECTRODES

and spalling and has some ductility, retaining these qualities at red heat. Deposits of the new material can be machine ground to a high finish. This alloy conforms to AMS Spec 5788 and Mil-R-17131 (Ships) Spec Mil-R-IIA140.

Control for Small Spot Welders

This type of electronic welder control is for use with manually operated small spot welders operating from single-phase alternating current. Such application requires a $^1/_2$ cycle (or less) precisely timed interval of weld current to be passed while the remainder of the welder sequence is controlled by other means.

The controls and transformer are housed in the one unit for compactness and efficiency. Formerly each component was separate.

This type of bench welder is used for such applications as instruments, vacuum tubes, telephonic equipment, household appliances, electronic apparatus, aircraft and automotive parts, gages and many others.

Welded Pin Bases

A change to welded base pins for fluorescent lamps from soldered or crimped pins, has been announced by Sylvania Electric Products, Inc., Salem, Mass.

Sylvania fluorescent lamps with the new welded pin bases will first be made available in the 40-w rapid start lamp, according to Lawrence P. Pleasants, Merchandising Manager of Sylvania's lamp division. Eventually all Sylvania fluorescent lamps will be supplied with welded pin bases, he said.

Welded pins effect a positive metal to metal contact, eliminating the possibility of corrosion or contact resistance. Mr. Pleasants described the new change as one of those "tremendous trifles" which help to produce a superior product. He said the improvement is being applied to rapid start lamps first because with this type of circuit a positive contact is very important.

Hard-Facing Rod

An improved cast alloy rod with excellent free-flowing characteristics has been announced by the Mir-O-Col Alloy Co., Inc., of Los Angeles, Calif.

Available for either electric or oxy-acetylene applications the rod, tradenamed Mir-O-Col No. 1, is designed primarily for single-pass applications on plow shares, plow disks and other agricultural equipment, where a thin overlay of extreme hardness is desirable.

Both Mir-O-Col No. 1 electric and Mir-O-Col No. 1 oxy-acetylene hard-facing rods incorporate an improved balance of alloys which provides better flow-

ing characteristics for smooth, fast deposit of weld beads.

Mir-O-Col No. 1 electric has a new flux coating which gives a more dense and porosity-free deposit, while Mir-O-Col No. 1 acetylene is centerless ground to remove scale and oxides promoting trouble-free deposition.

Literature describing the improved Mir-O-Col No. 1 hard-facing rods, as well as samples, is available upon request to Mir-O-Col Alloy Co., Inc., 312 N. Avenue 21, Los Angeles 31, Calif.

Microspooled Welding Wire

The Weldrod Co., Meadowbrook, Pa., originators of the Microspooled process, announces the development of chemically microfinished and electronically microspooled filler wire for "Mig" welding. Now available on expendable spools are aluminum, magnesium, stainless, titanium and other special alloy filler wires.

Weldrod Microspooled wire is available in sizes from 0.015 in. diam and larger, and adaptable to all makes of automatic and semiautomatic machines.

All wire is prepared to rigid specifications which permits a smooth and continuous feed of uncontaminated, chemically clean wire, thereby providing unsurpassed welding economies.

Data available upon request.

Fast-Working Electrode

A new contact-type electrode for high-speed production welding of mild and low-alloy steels is now available. It offers greater speed and easier welding than any conventional type electrode, according to the manufacturer. Introduced by Marquette Manufacturing Co., Inc., Minneapolis, it has a powdered iron coating and produces high-tensile strength and excellent ductility, depositing approximately twice as much weld metal per rod as conventional electrodes. This new rod, called Marq-Rod 12, is self-starting and restarting, virtually self-welding and self-cleaning with practically no spatter. Even inexperienced operators can learn to use it in a few minutes time. (Available in $^{3}/_{32}$ in. as well as regular sizes up through $^{1}/_{4}$ in.) Full information from Marquette Manufacturing Co., Inc., 307 E. Hennepin Ave., Minneapolis 14, Minn.

Paste Solder

Alpha Metals, Inc., announces "Swe-Tite" Paste Solder, a new solder paste for sweat soldering or tinning. The paste consists of a blend of 50/50 powdered solder and an active flux. For most applications cleaning is unnecessary. The paste is applied with brush or cloth, the parts

ARCOS FOR FINEST QUALITY WELDS

New Arcosite flux now makes possible submerged arc welding of stainless

Now you can enjoy full economy from submerged arc welding of stainless steel. New ARCOSITE FLUX and ARCOS CHROMAR (Stainless Steel) WIRE make this possible for the first time.

One reason for this is the skillful formulation and manufacture of ARCOSITE FLUX. Carefully controlled particle size of the flux assures you uniformity of arc action, alloy recovery, bead penetration and shape, and easy flow through flux feeding devices. Combined with the controlled analysis of ARCOS CHROMAR WIRE you get the advantages you need for successful welding: Mechanically sound, corrosion resistant welds . . . freedom from cracking . . . positive transfer of essential stainless elements. Write today for new Arcosite Flux Bulletin. Arcos Corporation, 1500 South 50th Street, Philadelphia 43, Pa.

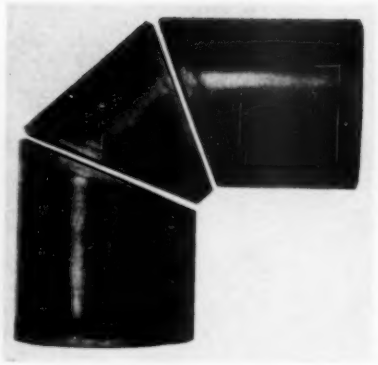
WELD WITH ARCOS

STAINLESS WIRE AND ARCOSITE FLUX

fitted together, and heat applied. After heating the small amount of flux residue can be removed by wiping the joint with a damp cloth.

The joints obtained by this method are as strong as those obtained by the conventional methods using a separate flux and solid wire. The fact that flux and solder completely cover the whole surface of the metals being joined insures a complete coverage and eliminates untinned spots.

Supplied in 1/2 and 1-lb cans with a free brush for each can. A Bulletin is available. Alpha Metals Inc., 56 Water St., Jersey City 4, N. J.



New Fittings

A new type welding fitting for use on low-pressure transmission and distribution lines in the gas, water and refining industries has been announced by George F. Stowell, Philadelphia manufacturer. Made from Schedule 40 seamless steel tubing, these fittings are precision-cut by machine into sections, trimmed with standard bevels and ready for strong V welding.

The Stowell fittings are said to simplify field installation and turning problems by eliminating complicated layouts and time-consuming hand mitering. Produced ready for installation, the sections have only to be lined up, tacked and welded. Being sectioned, they also have a degree of flexibility for contouring. For example, when pipe lines come together out of position for a standard fitting, these sections can be twisted approximately 5 deg to the position desired, then welded to make the joint.

All standard fittings—22 1/2 deg L's, 45 deg L's, 90 deg L's—saddles for T's, and special shaped fittings are available in any size from 6 to 24 in. For further information write to Gas Arc Supply, 223 N. 16th St., Philadelphia 2, Pa., the sole agent for Stowell.

Welding Rod

A new welding rod for die cast zinc, sheet aluminum, cast aluminum and galvanized tin has been announced by the Miracle Rod Company of Illinois. This new welding rod is especially made for use in industrial work wherever sheet or cast aluminum is used. Also ideal for use on aluminum boats, house trailers, auto bodies, etc. Packed, 35 rods to a cylinder. For catalog sheet, prices, etc., write to Miracle Rod Company of Illinois, 612 N. Michigan Ave., Chicago 11, Ill.

Low-Maintenance A-C Welders

A complete new industrial line of low-maintenance, high-speed a-c Bumblebee welders is now available from Air Reduction.

The new Airco Welders, NEMA rated 300-, 400- and 500-amp models, feature stepless current control, silicone insulation, aluminum coil windings and are equipped with a large current scale which the operator can read from a considerable distance without returning to the welder. Fingertip current adjustment and quieter operation are made possible by a new feature in which the coil supports float in a special rubber bushing.

Wide current ranges on the new Bumblebee (38–375 on 300 amp, 52–500 on 400 amp, and 65–625 on 500 amp) enable them to be used on practically all industrial applications ranging from light-duty, low-current to heavy-duty, high-current weld-

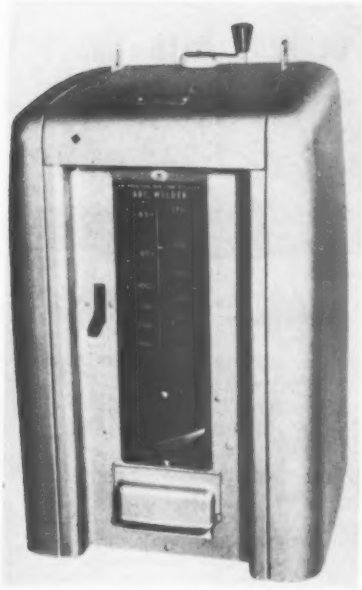
ACME *Automatic* WELDING POSITIONER and FIXTURES

Variations on units shown can be furnished to meet specific requirements.

THIS ACME FIXTURE ARRANGEMENT permits practically constant use of Automatic welding head by reloading opposite fixture during welding operation.

1. Vertical power traverse with up and down inching button.
2. Hand wheel on carriage with locking arrangement for setting automatic welding head in proper relation to work.
3. Positioner arm swings and can be locked in proper position to either fixture.
4. 22" diameter wheel shown on fixture.
5. Fixture equipped with Reeves variable speed for proper feet per minute with reversing control. Fixture with two set speeds can also be furnished.
6. Holding machine can be set in either vertical or horizontal position. Shown in 45° angle.
7. Cross slide adjustment for fine setting so welding head on arm can be placed at either fixture without further adjustment.
8. Heavy copper brushes and holders mounted directly back of fixture for ground.

ACME Manufacturing Co.
1400 E. 9 MILE RD., DETROIT 20 (Ferndale) MICH.



ing jobs. They are especially suited for heavy section welding where high current is desirable and when arc blow would otherwise cut welding speed and quality.

Optional equipment includes: An automatic hot start which provides an extra surge of current for easier starting, arc stabilizing capacitors, power-factor capacitors, primary switch, and a voltage reducing control and louvre canopy for adaption to outdoor applications.

Descriptive bulletin ADC 719 gives specifications and features of the new welders. Write Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Tube Tester

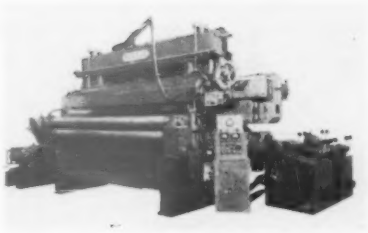
Electrical maintenance men at Ryan Aeronautical Co., San Diego, Calif., are saving time and trouble with a new tube tester which takes the guesswork out of troubleshooting. This device is used to test the large Thyratron electronic tubes which are used in all resistance-welding machines. At Ryan, where 100 welding machines of this type are in constant use, the tube tester is a valuable tool for pinpointing tube troubles and reducing machine downtime to a minimum.

The instrument was designed by electrical maintenance personnel and fabricated from used, surplus materials. It contains relatively few parts including a transformer, grid circuit, resistors, voltage regulator tube, rectifier, ammeter and voltmeter. The ammeter has been modified to register from zero to 5 amp. The voltmeter has been altered to register from −20 to +20 v.

George Pearson, of Ryan electrical maintenance, demonstrates the simplicity and compactness of the new tube tester which he helped design and build

Combination Welding and Trimming Machine

The Combined Welder and Trimmer includes all the essential features required for convenient handling of coil ends or flat sheets into position for submerged-arc or gas-shielded welding. It incorporates the time saving feature of welding and trimming the weld bead from both sides, at one time, without unclamping or transferring the welded seam.



It is arranged for welding and trimming 10-ft long seems in $^1/_{16}$- to $^1/_4$-in. stainless or other alloy sheets and strip. Pinch Rolls are furnished, the top roll being hydraulically loaded for holding the sheet flat during welding and trimming operation. A water-cooled, copper backing bar is supplied for welding operation. Any number of sheets of any width up to 10 ft long can be efficiently joined to make one long sheet for your needs. Morton Manufacturing Co., Muskegon Heights, Mich.

Table-Type Blast Cleaner

A new kind of table-type airless blasting machine for various cleaning and peening applications is being announced by American Wheelabrator & Equipment Corp., 1332 S. Byrkit St., Mishawaka, Ind. The machine, called a 72-in. Wheelabrator Swing Table, is distinct from other swing-table-type airless blasting machines in

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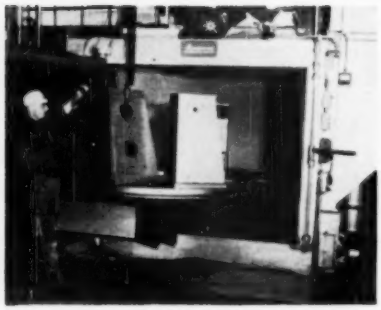


that it requires no pit at all for the abrasive hopper, whereas other types in the past have required them. The whole machine is built for floor level installation.

The machine has a 40-in. work height clearance and is meant to handle a wide range of work, such as that found in job shops. Intended for cleaning castings, forgings, heat-treated parts, weldments or stampings, the table can hold either a few large pieces, or hundreds of small parts at one time.

Home Soldering Kit

The very latest idea in homecrafter and hobby helps is a complete soldering kit designed by Weller Electric Corp., Easton, Pa. Inspired by interviews with interested bystanders during soldering demonstrations at "do-it-yourself" shows and retail stores, the new kit contains everything needed to make short (and easy) work of literally hundreds of jobs around the home and in the workshop.

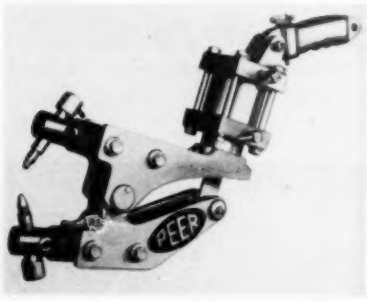
Attractively packaged in a sturdy metal carrying case, each Weller soldering kit includes a 250-w soldering gun (Model 8250A), an ample supply of Kester solder, one each of the new accessory cutting and

smoothing tips, a double-end wrench for speedy tip interchange or replacement and two instruction booklets containing expert instruction on all phases of soldering and home repair.

For further information write Joseph F. Whitaker, Weller Electric Corp., Easton, Pa.

Portable Gun Welders

Designed to "take the machine to the job," a new line of light-weight, heavy-duty portable gun welders has been introduced by Peer, Inc., to speed production on large sheet metal and wire assemblies. Gun welder units are available in 30 to 100 kva capacities for either air or air-hydraulic operation on 220-, 440- or 550-v power supplies. Due to the small number of parts, maintenance of the peer gun welders is simple. Six basic gun types (scissor type illustrated) are available for special applications. Associated operating equipment includes: water-cooled flexible cables, overhead suspended transformer with balancing arm, timing and contactor controls. Optional features include: ball bearing suspension, extra long or retractable stroke, spring balance for maximum vertical movements, special jaws and electrodes. Available for all peer portable gun



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CABLE SPLICERS

A permanent splice to repair broken welding cables. Install with a wrench (or solder if desired) for a quick and efficient connection. Insulated with a tough fibre sleeve, 2 sizes for cable #6 through 4/0.

Use TWECO cable connections to improve your welding efficiency. Ask for TWECOLOG No. 9 with complete specifications and prices.

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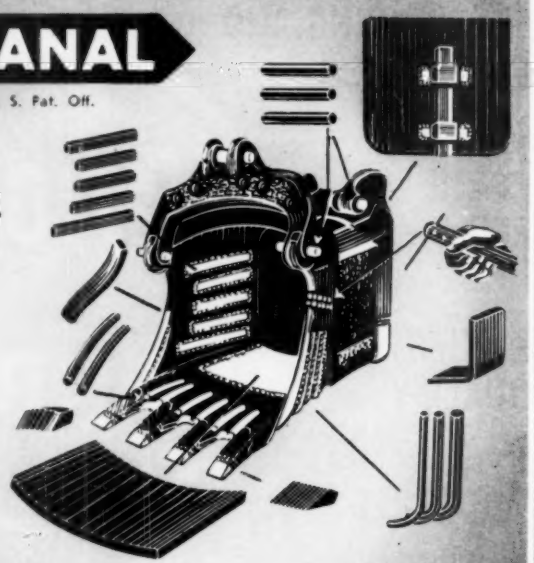

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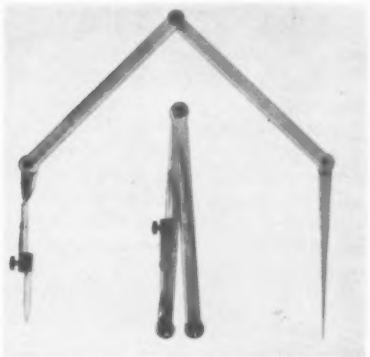
units. Literature and additional information may be obtained from Peer Inc., Benton Harbor, Mich.

New 24-In. Radius Marker

A new folding radius marker having a span of 24 in. is now being manufactured and marketed by the Contour Marker Corp., 1843 E. Compton Blvd., Compton, Calif.



Made of rustproof aluminum Dural, the new marker is designed to fold into a neat pocket-sized unit measuring only 9¼ in. and weighing only 8 oz.

Joints in the folding arms are equipped with special spring washers to maintain accuracy and rigidity for years of service.

Pencil holder is made to hold round or flat pencils, soapstone or steel point.

Every welder doing layout work will find this a very handy tool for many jobs.

Electrode Wire

The Air Reduction Sales Company has announced the availability of development quantities of an "activated" electrode, mild steel wire, for use in the consumable electrode inert-gas metal-arc welding process.

According to Airco, the activation agents change the burn-off rate so that stable spray-type transfer can be obtained on direct current, straight polarity without the need for oxygen additions to the shielding gas. Because these agents modify the penetration pattern, other "activated" wires will supposedly find many uses in welded build-up applications requiring minimum base metal pickup.

In addition, these wires permit the use of the process with standard alternating current welding power supplies. The excellent quality and high speed of the basic process can now be realized on applications where severe arc blow conditions may have previously prevented its use.

For additional information, write to Air Reduction Sales Company, 60 E. 42nd Street, New York 17, New York, Dept. 2032.

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by Waterman

MODEL S-15-A

Size:
12" x 6" x 7"
16¼ Pounds

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The WATERMAN TWIN POCKETSCOPE, model S-15-A, presents a new concept in multiple trace oscilloscopy with independent vertical channels each having a sensitivity of 10 millivolts rms/inch, and a response within −2 db from DC to 200 KC—a pulse rise time of 3 microseconds. These features combined with the provisions for intensity modulating either, or both, traces, results in greater flexibility. The sweep generator is operated either in the repetitive or triggered mode from 0.5 cycles to 50 KC with synchronization polarity optional. All attenuators and gain controls are of the non-frequency discriminating type. Remember that portability has not been overlooked! The amazing small size of the S-15-A tips the scales of opinion heavily in its favor. Imagine, all of these essential characteristics in an instrument weighing only 16¼ lbs. You can carry it to any job, anywhere!

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S-14-B WIDE BAND POCKETSCOPE
S-15-A TWIN TUBE POCKETSCOPE
RAYONIC® Cathode Ray Tubes
and Other Associated Equipment

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Product Design

Appleton, Wis.—Sixty-five members and guests of the *Fox Valley* Section met on Friday, September 17th, at the Elks Club in Appleton. An excellent talk on "Product Design for Welding" was given by John Mikulak AWS, Assistant to Vice-President in Charge of Manufacturing, Worthington Corp.

Mr. Mikulak's discussion covered manual, automatic and semiautomatic submerged welding. Slides were shown of actual applications and processes.

An after-meeting feature was the showing of slides through the courtesy of the Fox Valley Pheasant Farms and a commentary was given by Mr. Van Zeeland.

Alloy Electrodes

Appleton, Wis.—The October 15th meeting of the *Fox Valley* Section was addressed by R. K. Lee AWS, of the Alloy Rods Co. Mr. Lee's subject was "Alloy Electrodes."

Welding Clinic

Boston, Mass.—The *Boston* Section held its first monthly meeting of the 1954–55 season on October 13th in Cambridge, Mass., as guests of the Whitehead Metal Products Co., in conjunction with the opening night of their Welding Clinic and Demonstration, which ran through October 15th, in their new warehouse building just completed.

At least three hundred members and guests enjoyed a refreshment period followed by another of Dora Ferguson's excellently catered dinners.

Chairman Hogaboom introduced Messrs. Parry, Stewart, McWhirter and Blessington of the host company. Mr. Blessington welcomed the SOCIETY briefly and invited all present to visit the exhibitors' booths which were set up in adjoining bays of the building.

Low-Hydrogen Rods

Bridgeport, Conn.—Austin Hiller AWS, of the General Electric Co., York, Pa., was the guest speaker at the September 16th dinner meeting of the *Bridgeport* Section held at Rapp's in Shelton. "Low-Hydrogen Rods and Their application" was the subject of Mr. Hiller's illustrated talk.

An after-meeting feature was the showing of films by a Section member of a cruise on a yacht up the Housatonic River.

Tool and Die Steels

Buffalo, N. Y.—Cost reduction methods applicable to the manufacture and repair of special dies were explained and illustrated by R. K. Lee AWS, Vice-President of Alloy Rods Co., at the September 23rd dinner meeting of the *Niagara Frontier* Section held at the Sheraton Hotel in Buffalo. Limitations and precautions, not to be overlooked in the use of special tool and die steel electrodes, were also pointed out by Mr. Lee. Specific examples of time and cost savings were enumerated.

Recognizing the individuality of each application, Mr. Lee stated, is of primary importance in the successful welding of tool and die steels. Production methods have no place here. The care normally associated with tool room methods must be observed to achieve best results. Careful analysis, including classification as to the type of steel, proper preheat, correct welding procedure, quenching and sometimes annealing are all important.

Brazing

Chicago, Ill.—On Friday evening, October 15th, over 125 members and guests of the *Chicago* Section visited Armour Research Foundation of the Illinois Institute of Technology.

Following a tasty dinner in the Student Union, R. A. Lubker, Manager, Metals Research, described the activities to be seen during the tour of the Metals Department of the Foundation.

After the tour was completed, the group reassembled in Smith-Olson Hall of the Metallurgical-Chemical Engineering Building of IIT. There Dr. M. J. Day, Director of Program Development at ARF, presented a short history of Technology Center.

"What's Real New in Brazing" was the technical subject presented by Orville T. Barnett AWS, Supervisor of Welding Research at ARF. One slide, dealing with curves, evoked so much interest that the projectionist was reluctant to show the next slide in the series. Many of the basic metallurgical factors promoting good brazing action were reviewed.

Plant Visit

Cincinnati, Ohio—The Cincinnati Shaper Co. was host to the *Cincinnati* Section on the 28th of September. Eighty-one people, three of them member's wives, were conducted through the plant in groups of eight. The mercury vapor lighted plant exhibited very fine examples of the submerged-arc-welding process applied to welding gear rings to the web of the wheel; another eye catcher was the pantograph flame cutting. Since the press breaks and shears are made up of plate approximately 8 in. thick, it is only logical that multiple flame curring should be utilized to shape these components.

After witnessing the various operations of the plant the "tourists" approached the buffet luncheon with whetted appetites and a feeling of "Ah, Just the Thing!" The food was taken care of in good order and everybody settled back in their chairs. Everybody, that is, except the Section Chairman who gave a very enthusiastic start for the coming season. All of the Section Members feel certain that a very successful year will be enjoyed by the Cincinnati Section.

Chicago Section Meeting

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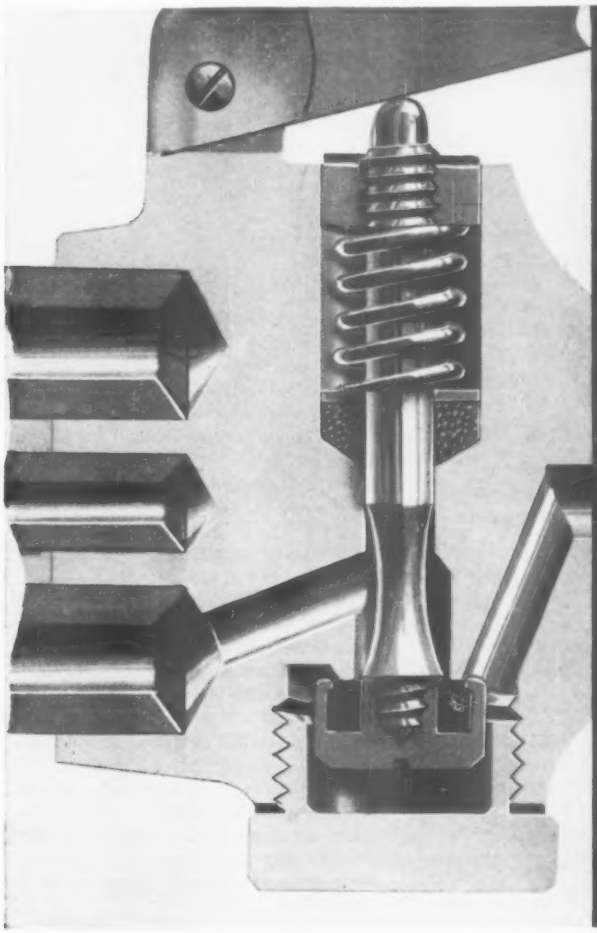
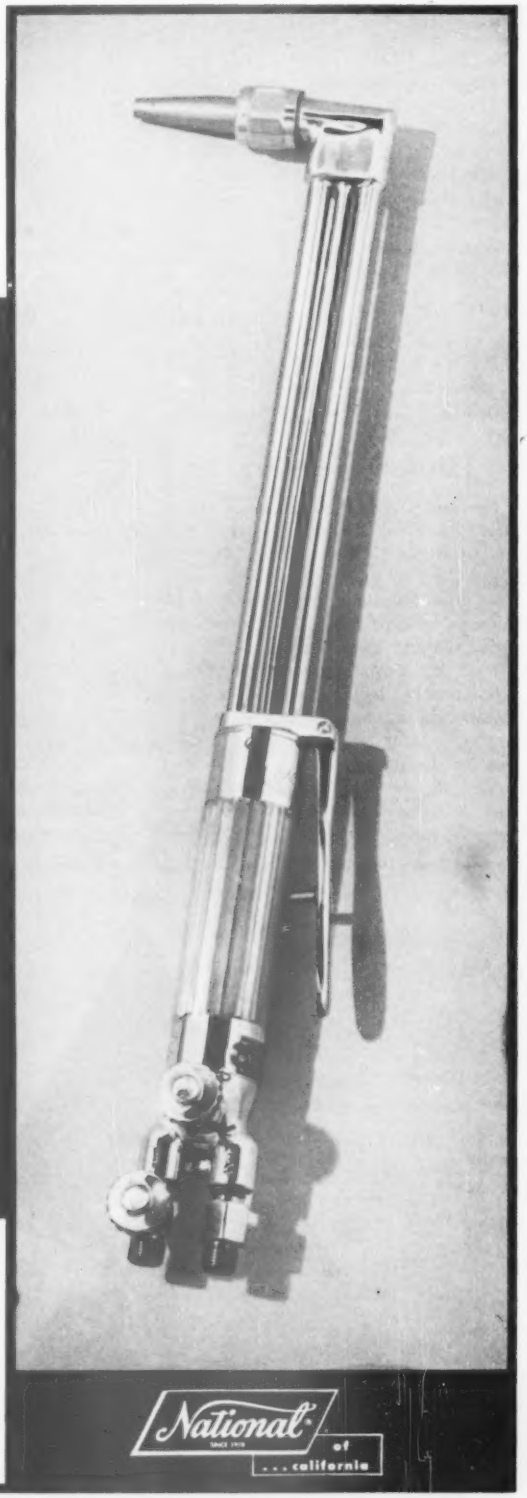


please note that no packing nut clutters up this leak free, unobstructed, high pressure oxygen valve. Constantly self-sealing, with an easily reachable and renewable seat, its large gas passages provide maximum flow capacity to eliminate preheating flame surge at the critical moment of cutting. No other cutting torch offers you so many outstandingly desirable advantages.



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Electrode Coating

Cleveland, Ohio—"It Isn't Mud" was the subject of a technical talk presented at the October 13th dinner meeting of the *Cleveland* Section held at the Manger Hotel. In his talk the speaker, H. F. Reid, Jr. AWS, of the McKay Co., York, Pa., covered the general subject of the arc-welding electrode industry. Chief topics of discussion were the functions of an electrode coating, materials used in electrode coatings, typical formulations for various AWS classification of electrodes and current manufacturing processes.

After the Technical Session a movie on the highlights of the Cleveland Browns football team of 1953 was shown.

High-Speed Rotors

Cleveland, Ohio—"Fabrication of High-Speed Rotors" was the topic of an address given by Harry A. Meyer of the American Blower Corp. at the opening dinner-meeting of the *Columbus* Section's 1954-55 season on October 8th. Mr. Meyer is at present the director of design at American Blower. Mr. Meyer addressed an audience of 50 in number, including 15 visitors.

There was a good turnout of student members encouraged by reduced dinner rates for the students. The section was honored by the presence of Jack York, Chief Welding Engineer for Huffman-Wolfe Mechanical Contractors. Mr. York is Past-Chairman of the Tri-Cities Section, Sheffield, Ala., and was in that office for two years. He is also Past-Chairman of the Holston Valley Section at Kingsport, Tenn.

Marshall Dasher, Educational Committee Chairman, showed the film "A for Atom" which was intended to present some background material for Prof. Alyea's talk on "Atomic Energy" at the next AWS meeting to be held in connection with the CTC Annual Dinner, on November 16th, at the Southern Hotel.

Plant Visit

Dayton, Ohio—A very successful inspection trip to the Bauer Bros. Co. plant in Springfield, Ohio, was made by 80 members and guests of the *Dayton* Section on October 12th.

The plant was interesting inasmuch as there are two types of manufacture. There is the Wire Division that specializes in making wire trays for the refrigerator, stove and general appliances industries. Here a great deal of automatic and semi-automatic equipment is used. These pieces are resistant welded 100%. They have a large installation of this type of equipment.

The other type of manufacture is a highly specialized heavy machinery type of operation, primarily producing processing equipment for the paper industry and some phases of the agricultural industry. Most of this equipment is custom made—there is a considerable amount of arc welding involved, plus heavy castings and heavy machine tools to machine these parts.

After the tour through this section of the plant, a demonstration was given on the operation of this equipment. First, cutting a log into chips, and then taking the chips and pulping them after which the pulp was taken and cleaned, so that the final cleaned pulp could be made into wallboard.

Prior to the tour, a short meeting was held at which Program Chairman Bob House outlined the various meetings for the remainder of the year. Glyn Williams was presented with a Past-Chairman pin for his work during the previous year. Mr. Appel, General Manager of Bauer Bros., then outlined the history of the company and their products.

Inert Arc Welding

Denver, Colo.—On October 12th over 50 members and guests of the *Colorado* Section met in the Festival Room of the Hotel Oxford for dinner. After a leisurely dinner a silent color film entitled "A Lake in the Desert," with narrating voice, was shown. It is a very interesting presentation of the Geologic History of Potash and its Modern Mining Process at Carlsbad, N. Mex. The use of maintenance welding below ground and above and its economy is surveyed in this picture.

The Technical Speaker was J. Warden Cunningham AWS, Process Engineer of Air Reduction Sales Co. who presented his educational talk on the Aircomatic Welding Process with slides showing types of bead, contour, penetration, etc., secured with different shield gas compositions, current densities and polarity. A silent slow motion picture in natural color of gas-shielded metal-arc welding with different gas compositions and straight or reversed polarity current, very clearly illustrated the process in new developments of metal arc welding.

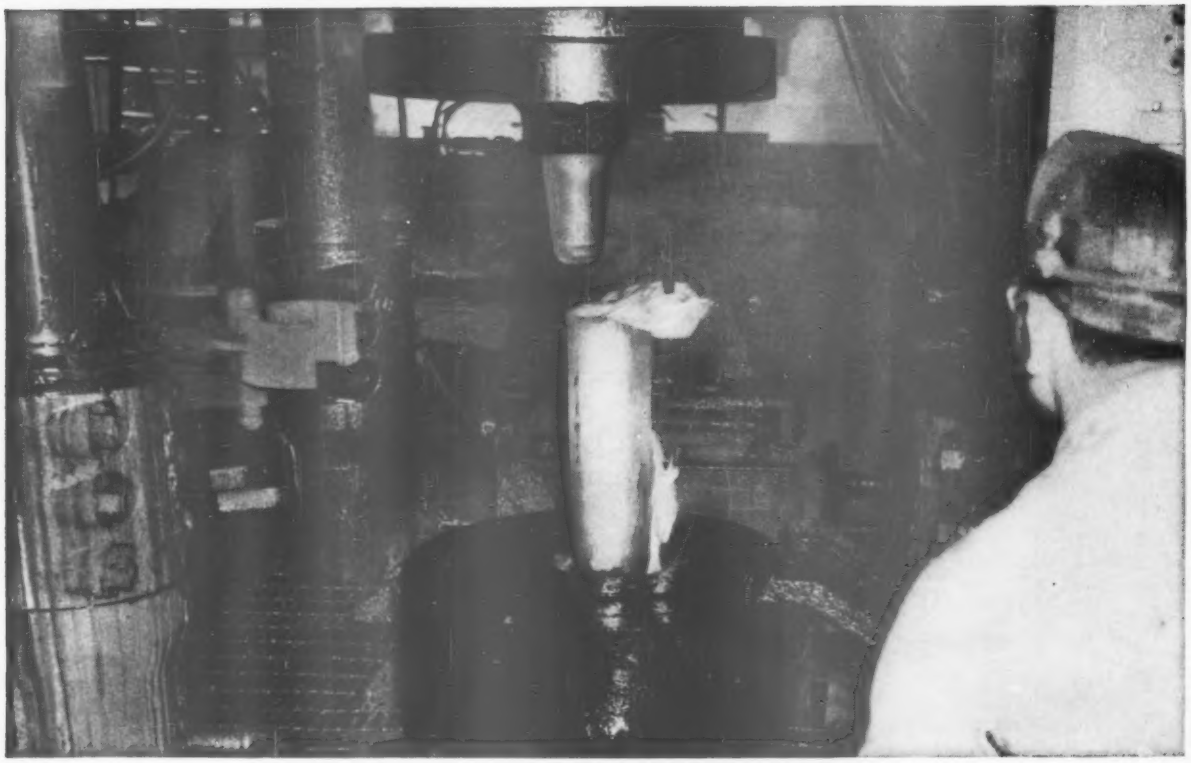
Automatic Welding

East Moline, Ill.—H. M. Downing AWS, of the Lincoln Electric Co., Chicago, was the guest speaker at the October 14th meeting of the *Illinois-Iowa* Section held in the American Legion club rooms. Mr. Downing's subject was on the automatic arc-welding process.

Inspection Techniques

Erie, Pa.—The *Northwestern Pennsylvania* Section held its regular monthly dinner-meeting on September 29th at the General Electric Community Center. Speaker at the meeting was Lew Gilbert AWS, of the Industrial Publishing Co., Cleveland, Ohio. Mr. Gilbert gave an

More than 350 Eutectic District Engineers join in wishing you and yours a Merry Christmas. In sincere appreciation of the friendship of weldors around the world, we resolve to help you enjoy a successful and prosperous New Year. Eutectic Welding Alloys Corporation.



Die Pot Life Increased 350 Per Cent

A deposit of HASTELLOY alloy C hard-facing rod has more than tripled the service life of the die pots used in this slugging and piercing operation. The hard-faced parts are exposed to severe impact and abrasion at high temperatures. Press tonnages required to perform the operation have been reduced from 30 to 50 per cent since the pots have been faced with HASTELLOY alloy C. This rather unusual plus value is due to the low friction characteristics of this nickel-base alloy.

Resists Chipping and Spalling

HASTELLOY alloy C is a tough, machinable, hard-facing alloy that can be applied to all common die steels. It has high tensile strength, good ductility and excellent resistance to chipping and spalling. It can be applied by the metallic-arc process, flows smoothly, and produces sound deposits. No special heat-treating or cooling procedures are needed.

No Grinding or Peening

When deposited, HASTELLOY alloy C has a hardness of 210 Brinell, and can be machined easily by ordinary die-sinking tools. Then the deposit work hardens, in service, to about 375 Brinell without deformation. Its work-hardening characteristics eliminate the necessity for peening the deposit to obtain maximum wear-resistance.

For information on procedures for applying and for available sizes and prices, write for the booklet "HASTELLOY Alloy C—A Machinable Hard-Facing Alloy."

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Photographs taken at October 27 meeting Houston Section held in Ben Milam Hotel with an attendance of 140. The group of three men are, left to right, James Earthman, Section Chairman; William H. Funk, Lukens Steel Co., speaker; and H. H. Wehner, Jr., Program Chairman

excellent nontechnical talk on the subject "Inspection Techniques for Quality Welding."

An after-meeting feature was the showing through the courtesy of Metco of a film entitled "Metallizing—Its Practical Applications."

Battle of the Sections

Erie, Pa.——Special guests at the October 27th meeting of the *Northwestern Pennsylvania* Section held at the Polish Falcons Club were Fred J. Plummer AWS, President, and Clarence Jackson, No. 1 District Director. The speakers extended greetings and reports on the latest National and District activities.

A "Battle of the Sections"—Niagara Frontier, Northwestern Pennsylvania and Cleveland—Finished with a final score of 122 for Niagara Frontier, 128 for Northwestern Pennsylvania and 155 for Cleveland. Each member in the audience was furnished with question-and-answer sheets to enable them to keep a jump ahead of the experts. Ten points each were allowed for all questions except jackpot questions which were allowed 20 points each.

Welding Progress

Fort Wayne, Ind.—A very interesting meeting of the *Anthony Wayne* Section was held at the Chamber of Commerce Building in Fort Wayne, Ind., on Friday evening Oct. 22, 1954.

Following the dinner, attended by some seventy members and guests, Glen Birt AWS, Vice-President of the American Steel Dredge Co. of Ft. Wayne, Ind., gave a very good talk on welding development and stressed the advantages of management support of the AWS.

After Mr. Birt's interesting talk, the Alcoa Sound Picture, "Welding Advances in Aluminum," was shown.

Hard Facing

Houston, Tex.—The first meeting of the new season for the *Houston* Section was held at the Ben Milam Hotel, Sept. 22, 1954.

After dinner, R. P. Culbertson AWS, of Haynes Stellite Co., gave a very good talk on hard facing. Mr. Culbertson covered almost all phases of hard facing and his talk was very enlightening.

One hundred and eighteen members and guests were present for the dinner meeting.

Plant Tour

Houston, Tex.—The *Beaumont Division* of the Houston Section took part in a most interesting plant tour of the Bethlehem Steel, Ship Building Division, on October 21st. During the two-hour visit a number of shops and divisions of this plant were visited. Everyone was very much impressed with the offshore drilling barges which were nearing completion. These barges are able to set up and drill in 100-ft depths in the Gulf of Mexico. These barges could not have been built were it not for the new welding techniques and procedures.

Powerama Exhibit

Indianapolis, Ind.—The *Indiana* Section held its first meeting of the 1954–55 season at the Powerama Exhibit of the Allison Division of General Motors Corp. John T. O'Brien, Supervisor of the exhibit, was the host. After treating the members to a delightful three-course meal an explanatory moving picture was shown, followed by visits to individual booths which were manned by trained personnel of Allison Division. Ninety-six members and guests were in attendance and the program was enjoyed by all.

Inert-Arc Welding

Kansas City, Mo.—The *Kansas City* Section held its monthly meeting on Thursday, October 14th, at Fred Harvey's Pine Room in the Union Station, Kansas City, Mo. H. DeWitt Beeson of the Aluminum Company of America at Kansas City was the coffee speaker and his subject was "New Aluminum Alloy Nomenclature." After fully discussing the new symbols, Mr. Beeson passed out charts showing the old and new symbols. The main speaker of the evening was J. Warden Cunningham AWS, Process Engineer from Air Reduction Sales Co. in New York, whose subject was, "New Developments in Inert-Gas-Shield Consumable Metal-Arc Welding." Mr. Cunningham accompanied his talk by slides showing the development of the process and bringing it up to date with all of the new wire and gas mixtures that have been developed recently. At the conclusion of his talk, he showed a high-speed movie that enabled the audience to actually see the metal being transferred across the arc. Evidence of interest in Mr. Cunningham's talk on the Aircomatic process was the fact that we had one of the largest turn-outs to a technical meeting in the history of the section.

Power and Heating

Hollis, Long Island.—The October meeting of the *Long Island* Section, held on the evening of October 14th at Anselmi's Restaurant, Bethpage, L. I., featured two speakers.

John McDougall, General Distribution Engineer of the Long Island Lighting Co., spoke on "General Power Requirements for the Welding Industry" and Nelson B. Stevens of the Induction Heating Equipment Corp., Brooklyn, N.Y, spoke on "Practical Application of Induction Heating in the Aircraft Industry and Small Welding Shops." Both talks were quite informative and well received by the membership.

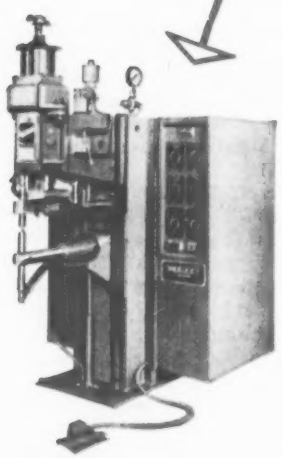
The usual social period preceded the Dinner and Technical Session.

Rectifier Welder

Los Angeles, Calif.—G. K. Willecke AWS, Physicist for the Miller Electric Manufacturing Co., Appleton, Wis., gave an excellent discussion on "The Rectifier Type D-C Welder" at the October 21st dinner meeting of the *Los Angeles* Section held at Swally's Cafe.

Door prizes were donated by the Pacific Metals and were won by John B. Wiley and Paul Montagne.

Sciaky Three-Phase Welder at Buckeye Div. of Mardigan Corp. of Wooster, Ohio.



Sciaky Three-Phase Improves Design, Appearance, and Jumps Production 375%

The use of Sciaky patented Three-Phase balanced load, high power factor, resistance welding enabled Buckeye to improve the design and jump production 375% on pot and pan covers. Sciaky Three-Phase readily solved a limited power problem. Fabricating costs were reduced sharply, and the basic design of the product was greatly improved.

In welding, a disc and a drawn .025 aluminum cup are placed over the lower spot welding electrode. The .104 aluminum cover is inverted over the cup and one stroke of the welder completes the assembly. Then the hollow knob is screwed into place completely covering cup and flush with the cover. The airspace within the knob protects miladies' fingers from burns. Write for complete details of the welding operation at Buckeye in "Resistance Welding at Work," Vol. 4 - No. 2.

Buckeye's improved design for cover knobs is another fine example of Sciaky basic thinking — welders designed to do *more useful work* at *lowest operating cost* with *maximum reliability.*

Largest Manufacturers of Electric Resistance Welding Machines in the World

SCIAKY

Sciaky Bros., 4919 West 67th Street, Chicago 38, Illinois

Silver Brazing Titanium

Los Angeles, Calif.—*The Aircraft and Rocketry Panel* of the Los Angeles Section held its October meeting on the 7th at Swally's Key Club. Dr. Nathane A. Tiner, Metallurgist, North American Aviation, Inc., Downey, Calif., gave a very interesting presentation on the "Metallurgical Aspects of Silver Brazing Titanium to Titanium."

Doctor Tiner described titanium brazing methods and techniques for unalloyed titanium structural joints. Upon establishing applicable processes and some of their advantages and short comings he dwelled on applicable brazing alloys and filler metals. The use of fine silver as one of the best filler metals was explained in detail. The development of low, medium and high shear strength brazes in unalloyed titanium was explained with slide photomicrographs and X-ray diffraction patterns.

Two door prizes were awarded to people attending the meeting. The first prize was won by Ed Scott, representing Linde Air Products, and second prize was won by John Mannon from North American Aviation, Inc. The door prizes were provided by the John Wiley Distributor Co.

Tractor Production

Louisville, Ky.—The regular monthly dinner meeting of the *Louisville* Section was held on September 28th at Korfhage Tavern. A nontechnical talk on "Welding in Farm Tractor Production" was given by William C. Davis of the International Harvester, Louisville.

New Madison Section

Madison, Wis.—The newly organized *Madison* Section held its first official meeting on September 30th with 60 attending.

The group enjoyed a very informative talk by Joseph Humberstone, First Vice-President [illegible], former president of Ohio Chemical and now president of the Air Reduction Sales Co.

The Section now has 65 members with four supporting companies. The supporting companies are: Krueger Fabricating Co., Ohio Chemical, Carnes Manufacturing Co. and the Oscar Mayer Co.

Walter Griskovick, Methods Engineer with Ohio Chemical Co., was elected Chairman of the new Section; Prof. Howard E. Adkins, Mechanical Engineering, University of Wisconsin, 1st Vice-Chairman and Fred Theiler, Madison Vocational School, Secretary-Treasurer.

Plant Tour

Marion, Ohio—The second regular meeting of the 1954–55 season for the *North Central Ohio* Section was held in the Marine Room of the Globe Hotel in Mt. Gilead, Ohio. Seventy-three members and guests attended the dinner meeting.

John C. Cotner, President and General Manager of the Hydraulic Press Manufacturing Co., was the coffee speaker. Mr. Cotner reviewed the growth of welding during his career in metal working industries and particularly told about the growth of welding at HPM. He reviewed the history of the company and told the points of interest to note during the plant tour. The meeting then was adjourned and small groups were taken through the two major plants of the Hydraulic Press Co.

The entire operation—from receipt of raw steel through the flame cutting, fabricating and welding departments—was observed. In addition, the machining and assembly operations were shown. All members and visitors attending this plant tour were very much impressed with the attractive modern plant and the massive work being performed.

Presentation of pen to speaker L. M. West of the Douglas Aircraft Co. at the September meeting of the Los Angeles Section. Shown left to right: C. C. Harrison, Process Engineer Division Head, Douglas Aircraft Co., Long Beach; L. M. West, Welding Engineer, Douglas Aircraft Co., Long Beach; J. B. Ross, Sales Manager of Handy and Harman; R. C. Hayes, Welding Engineer, Douglas Aircraft, Long Beach and Chairman Aircraft and Rocketry Panel; and C. B. Smith, Supervisor Process Engineering, Douglas Aircraft, Long Beach and Secretary of the Los Angeles Section.

Meeting Dates

Milwaukee Wis.—The regular monthly meeting dates for 1955 of the *Milwaukee* Section are as follows: January 21st. February 25th, March 25th and April 22nd. The annual party of the Section will be held on May 21st. The Educational Program will take place on January 10th, 17th, 24th and 31st.

Reactivation

New Orleans, La.—The following communication has been received from Buddy Dukes concerning the reactivation of the *New Orleans* Section.

"Greetings with a big hello from an old chapter that took an exit for a few years. Yes, it is us from down ole' New Orleans way. Some ten years or so ago with the world situation in a bad state for everyone, the New Orleans chapter of the AWS went inactive indefinitely.

"Now we of the New Orleans chapter are on our comeback as strong as ever. Back in the spring several people affiliated with welding began working on reactivating this chapter. After much hard work by our officers and committee chairmen, and several others not mentioned, memberships began to roll in. Reaching the minimum number of fifty members was the real question.

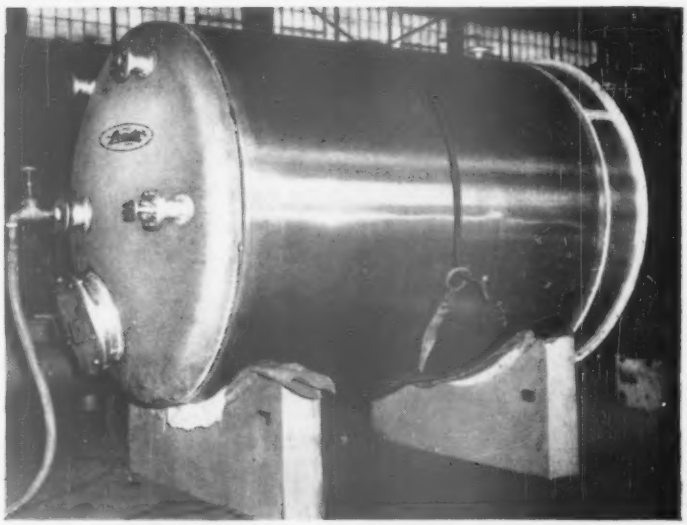
"Our minimum was reached and temporary officers were named. The chapter has not let down in the least. With the work of the chapter as a whole we have about ninety members now and plan to have over one hundred by January 1 and a hundred and fifty a year from now.

"The chapter held its first regular technical meeting last August 14th and many plans were discussed for the future. Perry Jones of the American Metal Society announced that lectures on welding and metallurgy will be held at Tulane University this fall. This will be sponsored by the American Metal Society in conjunction with the AWS.

"Chairman Bill Blackwell and Technical Chairman Ted Fatland have arranged with the School of Engineering at Tulane for welding classes to start the beginning of the spring semester. Credit for these courses will be decided upon by the Dean of Engineering.

"The Program Committee has worked out a schedule of speakers for future meetings. Speaker for our last meeting was A. E. Pearson, District Director, Southeastern District of AWS from the Ingalls Iron Works Co., Birmingham, Ala. Mr. Pearson's subject was 'Welded Building Con-

RADIOGRAPHY makes positive about negative pressure



Specifications for this tank—designed to operate from vacuum to 25 pounds' pressure—called for welded 2S aluminum. This, as welders know, could cause problems. But the builders called on radiography. Here is what they say:

"X-rays played a very important part in the extensive research to determine the most suitable method of welding the vessel. Without the use of x-ray we might never have obtained the high quality and uniform results."

Which shows two important facts. First, that radiography proves the soundness of welds. Second, that it expands the use of the welding process.

This is good reason that today more and more welders make use of radiography. If you would like to know how it can help your business, get in touch with your x-ray dealer and talk it over.

EASTMAN KODAK COMPANY
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Radiography . . .
another important example of Photography at Work

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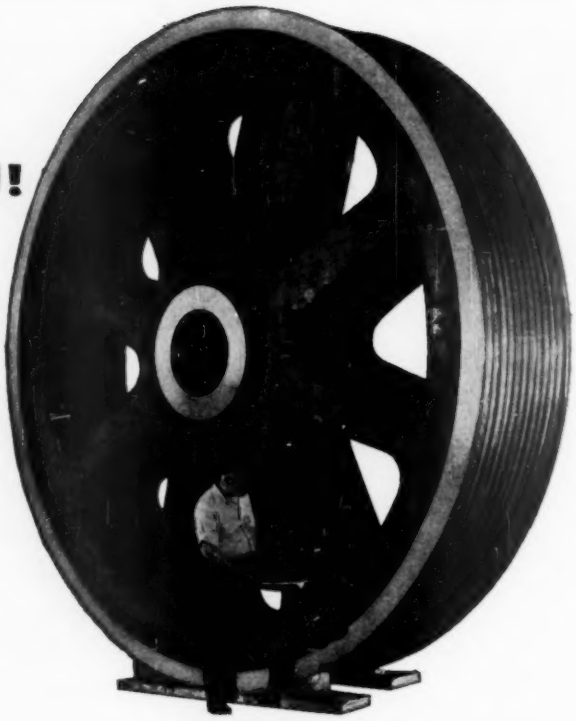
IF YOUR PRODUCT IS WELDED A.W.S. CAN HELP YOU!

Many of the advancements in welding design these days spring directly from the membership of the American Welding Society.

Most of the engineers in welding industries depend on A.W.S. to keep in touch with technological advancements outside the boundaries of their own plant and their own day-by-day welding experience.

Many of their achievements in saving weight, improving products and reducing manufacturing costs can be traced directly to discussions and exchange of ideas at their frequent A.W.S. section meetings.

If you use welding in your business, make sure that your welding people are taking full advantage of the opportunities A.W.S. offers.

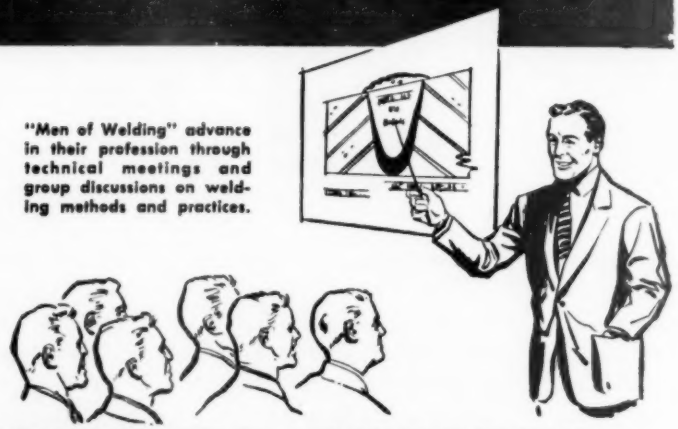


This giant welded sheave is 15 feet in diameter, the hub is a center bored forging, and the entire weldment weighs 34 tons. — Photo courtesy Bethlehem Steel Co.

A. W. S. Builds "MEN OF WELDING"

There are 66 active local sections of A.W.S. covering the entire United States. The 9,683 members of A.W.S. hold monthly technical meetings and plant visitations where they observe practical solutions to typical welding problems and study new welding methods. They receive accurate information on welding design, fabrication and maintenance through discussions with the best welding minds in the nation and authoritative printed reports.

"Men of Welding" advance in their profession through technical meetings and group discussions on welding methods and practices.



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struction," with a discussion and slides on the late construction of the all-welded Texas Building in New Orleans. The discussion was broken down to rigid, semi-rigid and flexible joints, with slides to show the distinction between each. The discussion was well enjoyed by all those present.

"Through the series of monthly meetings, there will be informal parties and picnics. Some meetings will include movies on subjects that do not involve welding, such as sports, underwater movies, etc. Every effort will be put forth to obtain a well-rounded entertainment program for the chapter and each individual in the chapter.

"This is Publicity Chairman Buddy Dukes of James F. O'Neil Co., Inc., and Clayton Bach of Kaiser Aluminum & Chemical Corp., along with all the others of the New Orleans Chapter of AWS, inviting all of you interested in welding to come around and see us."

Meeting Program

New York, N. Y.—The following is the program of meetings of the *New York* Section for the remainder of the season:

Jan. 11, 1955—"The Selection and Application of Hard Facing Alloys." Speaker to be announced.

Feb. 24, 1955—Joint Meeting with Naval Architects (Antlers Restaurant, 67 Wall St.). Panel on Industrial Welding Subjects.

Mar. 8, 1955—"Welding Titanium and Titanium Alloys." John J. Chyle, Director of Welding Research, A. O. Smith Corp.

Apr. 12, 1955—Subject and speaker to be announced.

May — 1955—Annual Dinner.

Meetings will be held at Schwartz's Restaurant, 54 Broad St., New York City, except where otherwise noted.

Welding Specifications

New York, N. Y.—"Welding Processes and Welding Specifications" was the subject presented to the *New York* Section on October 5th. Roger W. Clark AWS, General Electric Co., Sub-Section of Materials and Processes Laboratories, was the speaker. Mr. Clark presented the History of the Development of Welding and the processes involved. The necessity of a Uniform Code for Qualification of Processes and Welders was outlined together with heat treatments and the use of proper welding rods. Mr. Clark also stressed the importance of Supervision, which included Personnel Training and Quality Control.

The talk was given on a general basis and, as a consequence, opened up a lively discussion period.

Many distinguished visitors attended the meeting. Among them were F. L. Plummer, National President AWS, and J. E. Dato, Chairman, National Membership Committee AWS.

The meeting was held at Schwartz's Restaurant, 54 Broad St., New York City, where dinner was served prior to the technical session.

Mr. Kugler, Technical Chairman, introduced the speaker.

Electrodes

Oak Ridge, Tenn.—The September meeting of the *Northeast Tennessee* Section was held on the 20th in the Knights of Columbus Hall, Oak Ridge. The speaker, August Clemens, Jr. AWS, Arcrods Corp., Sparrows Point, Md., explained the major differences between the common types of mild steel coated electrodes and listed the advantages of each. The evolution of low-hydrogen electrodes was described along with their varied applications. A brief discussion of the use of low-alloy electrodes was also presented. The use of frequent examples helped to make this talk very interesting and informative. Mr. Clemens' talk was very well received and brought forth a stimulating discussion period.

Weldability Problems

Philadelphia, Pa.—On Monday, September 20th, the *Philadelphia* Section held its initial technical meeting of the season at the Drexel Institute of Technology where 200 members and guests were in attendance. Prior to the meeting, 75 members gathered for dinner in the colorful college cafeteria.

The evening's program was under the direction of S. Baum, Chairman of the Educational Committee, who gave a brief outline of the two courses in welding engineering, which are sponsored by the Section and will be given at the Drexel Evening College again this year.

The principal speaker of the evening was Robert E. Somers AWS, Welding Engineer for the Bethlehem Steel Corp. He gave a most interesting talk on "Everyday Weldability Problems." Mr. Somers' presentation was directed toward the solution of weldability problems with emphasis on the Welding Engineer's responsibilities in: (1) proper selection of base and filler materials for the job; (2) proper and adequate design for welding; (3) proper application of sound welding engineering principles during fabrication. The talk

September Meeting Philadelphia Section

Examining welded specimen. Left to right; David Thomas, Jr., Robert E. Somers and S. Baum

was well received as indicated by the length of the question period.

In conjunction with the meeting, several local metal products manufacturers who specialize in welded fabrication exhibited their product in sample or model form; also, some of the latest designs in welding equipment and processes were on display for the meeting.

Some of the displays were donated to the college for use in the AWS sponsored courses.

Industrial Plant Visit

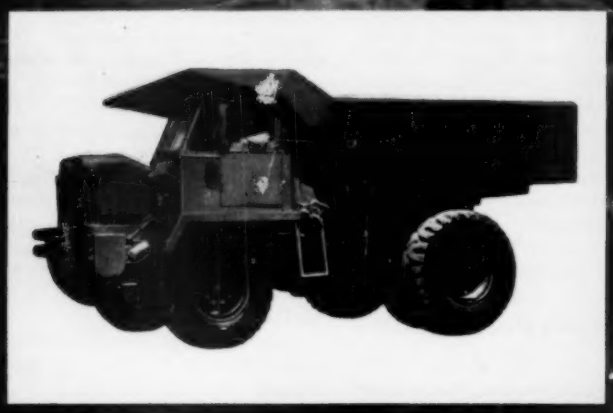
Philadelphia, Pa.—The second meeting of the *Philadelphia* Section was held October 18th at 8:00 P.M. in the conference room of the main offices of the Yale & Towne Manufacturing Co.—Material Handling Division. This huge modern industrial plant is surely one of Philadelphia's finest and houses under one roof many of the most modern phases of welding and cutting equipment.

O. Carliss, Director of Engineering, was the speaker and gave an excellent talk and general rundown on the part that welding played in the manufacture of lift trucks and chain hoists. Mr. Carliss pointed out that the use of AWS symbols have become standard practice throughout the Welding Department, and that resistance welding of chain is done on a large scale in this plant.

The meeting was adjourned at 8:45 P.M. and conducted tours were provided for small groups through the plant. The groups went through the submerged-arc welding section to the chain shop, then to the fork, channel and carriers fabrications lines. The tour continued through the flame cutting section where many of the multiple torch machines with modern tracing heads cut to shape many of the component parts for lift trucks. The tour continued through the structural fabricating and welding department, ending at the truck assembly lines.

An expression of appreciation was extended to Mr. Carliss and to Robert Ben-

WELDING ARCS NEWS



BY SWITCHING FROM CONVENTIONAL E6012 ELECTRODES TO G-E STRIKEASY 1 IN WELDING FRAMES FOR 20-TON END DUMP TRUCKS

WELDING FOREMAN FOR DART TRUCK CO. SAYS:

"Speed?—G-E Strikeasy 1 electrode saves us

"Not only does General Electric's Strikeasy 1 electrode give us tremendous savings . . . it offers an operating ease that my men and I have never experienced in all our years in welding."

This is the conclusion reached by Mr. E.A. Gassman, Welding Foreman for the Dart Truck Co., Kansas City, Mo.—manufacturers of the largest dump trucks in the world.

DART SAVED OVER 2 MAN-DAYS PER TRUCK, when it switched to the G-E Strikeasy 1 electrode for the welding of frames for its Model 20-S 20-ton end dump trucks. Dart says that this represents a 50% decrease in welding time over the conventional E6012 electrodes which were formerly used.

Such high speeds are realized because Strikeasy 1 uses a nonconductive rutile type coating enriched with powdered metal. When an arc is struck, the metal particles melt off to form part of the bead.

STRIKEASY 1 ELECTRODE IS EASY TO USE. A contact-type electrode, it forms a finely rippled bead when you simply drag it over the job. And less skill is required to hold arc length.

Also, slag practically peels off Strikeasy 1 welds without excessive chipping and cleaning. All this means that Strikeasy 1 helps cut down on operator fatigue—slashes training time for new operators.

IMPROVE YOUR COMPETITIVE POSITION, and cut labor and overhead costs by using Strikeasy 1 to speed up those applications where you are now using

General Electric Balanced Electrode Design Gives Better Over-all Results

Within any given electrode class, G-E electrodes give your welding applications a balanced combination of speed, weld-quality, and ease of use—for better over-all results. Application tested, "balanced design" is part of the entire G-E line of electrodes—the most complete line in industry.

"QUALITY WELDS" was the order for this Dallas skyscraper. G-E W610A electrode provided necessary fast strength welding.

BALANCED DESIGN pays off as G-E type W2308 stainless-steel electrodes are used in out-of-position welding this large cone.

(SEE INSET), DART TRUCK SAVES OVER TWO MAN-DAYS PER TRUCK. SEE STORY BELOW.

over 2 man-days per truck!"

conventional E6012 class electrodes.

Check your G-E welding distributor's name at the right and in the yellow pages of your phone book; ask him for: GEC-1231—Bulletin on Strikeasy 1; GEL-1196—Wall Chart for Selecting Stainless-steel Electrodes; GED-1634—Electrode Catalog, a pocket-size guide to electrode selection and application. General Electric Company, Schenectady, New York. 710-19

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Connecticut: Hartford, New Haven—Harris Company

Florida: Hollywood—Florida Gas & Chemical

Georgia: Athens—Welding Gas Products; Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies; Gainesville—Welding Gas Products

Idaho: Boise—Gate City Steel

Illinois: Chicago, Moline, Morton, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—PerryWelding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Wichita—Standard Products

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City; Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales Corp.

New Mexico: Albuquerque—Industrial Supply Co.; Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; New York—Welding Sales Corp.; Syracuse—Welding Engineering & Equipment

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Oklahoma City—Hooper Supply; Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Beaumont—H. & W. Welding Supply; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Orange—Marine & Petroleum Supply; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—McGinnis Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Wyoming: Cody, Lovell—Valley Motor Supply Co.

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

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to WELD or CUT

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well AWS (Structural Department for Yale & Towne) who made the plant tour possible through his invitation.

Stud Welding

Pittsburgh, Pa.—New developments in the application of stud welding in the basic steel producing industry and a wide range of metal-using fields, were discussed by R. C. Singleton AWS, Manager, Industrial Sales Division, Nelson Stud Welding Division, Gregory Industries, Inc., Lorain, Ohio, at the October 20th dinner meeting of the *Pittsburgh* Section.

Slides showing how stud welding is used for slab and ingot identification in steel mills and as a materials handling aid in forging, seamless tube extrusion and other operations, were included in the illustrated talk.

Preceding his talk, Mr. Singleton showed the Nelson Stud Welding film entitled "Split-Second Fastening."

Brazing and Cutting

Portland, Ore.—The second meeting of the season of the *Portland* Section was held on October 12th at the Heathman Hotel. A social gathering preceded dinner. A total of 30 members and guests were on hand to hear a fine lecture by J. Marden AWS, of the Eutectic Welding Alloys Corp., Los Angeles, Calif. Mr. Marden's talk and the accompanying motion picture were devoted primarily to late developments by their company and the industry to welding particularly to brazing, piercing and cutting with the arc.

Richmond Program

Richmond, Va.—The following is a program of meetings for the remainder of the season for the *Richmond* Section:

Jan. 20, 1955—First meeting following the holidays. Immediately after the business meeting, G. E. Linnert AWS, of Armco Steel Corp. will present a very interesting program.

Feb. 17, 1955—Richard K. Lee AWS, of Alloy Rods Co., York, Pa., will speak on "Recent Developments in Alloy Electrodes."

Mar. 17, 1955—A. N. Kugler AWS, Chief Welding Engineer of Air Reduction Corp., New York, N. Y., will show pictures and present a speech on "Jigs and Fixtures for Welding."

Apr. 19, 1955—Lincoln Electric Co. of Cleveland, Ohio, will have Van Rensselaer P. Saxe AWS, Engineer, of Baltimore, Md., presenting slides and talk on "Building Structure and the Importance of Saxe System Welded Connection Units for Welded Assemblies."

May 19, 1955—The last meeting before the summer vacation will be highlighted by a speaker from Reynolds Metals Co. of Louisville, Ky., Chas. Bruno AWS Chief Welding Engineer, who will discuss "Latest Methods of Joining Aluminum by Welding, Brazing and Soldering."

June—The month for the last meeting of the SOCIETY. This meeting will be held at the picnic grounds on Belle Isle. "Fun for Young and Old." Prizes will be awarded to persons holding admission tickets. The date has not been set.

NOTE: Prizes will be given away at each meeting during the 1954 and 1955 season. In order to be eligible to win one of these, a signed returned card should be in the Secretary's hands, prior to each meeting date, and not later than Tuesday.

Panel Meeting

Saginaw, Mich.—Ninety-five members and guests of the *Saginaw Valley* Section attended the dinner meeting held at the High Life Inn in Saginaw, Mich., to hear three of its own members discuss the Different Aspects of Submerged Arc Welding.

J. B. Quigley AWS, District Representative of Lincoln Electric Co., talked on the "Fundamentals of Submerged Arc Welding." Mr. Quigley discussed the factors to be considered in applying submerged arc welding, such as voltage, amperage, flux, speed of travel, position of welding wire in relation to work, type of work, setup involved and type of welding head. He also discussed the applications of hard surfacing by means of the submerged arc method.

R. R. Lyman AWS, Supt. of the Boiler Shop Wickes Boiler Co., talked on "Heavy Application of Submerged Arc Welding." Mr. Lyman stated that work in their shop involved material up to 3½ in. thick, most of which is X-rayed in its entirety. He went through and discussed the steps that the material follows until it is a complete pressure vessel. These steps are: burning to size, planing the bevels, crimping and forming edges, rolling to shape, welding inside seams, installing head and welding inside, back chipping, preheating on heavier material, welding outside, grinding for X-raying, repair if necessary, re-X-raying, stress relieving, and testing under pressure.

W. F. Williams AWS, Assistant Welding Engineer of Buick Motors Division, Flint, Mich., talked on "Adaption of Submerged Arc Welding to Fully Automatic Welding." Mr. Williams stated that their work was of a highly repetitive nature and that the standard stock head needed many modifications to suit their type of work. He explained their work as "Automatic Automatic Welding," where the material is placed in a jig, a button is pushed, the head moves down, the rod contacts the work, the flux flows around the rod, the arc starts, the work starts moving, the weld is made, the arc stopped and the cycle reversed. Most of this is obtained by ex-

tensive use of sequence timers. Mr. Williams went on to explain in detail how such a sequence of operation is obtained and to describe some of the problems encountered.

Election of Officers

Richmond, Va.—The *Richmond* Section announced the election of officers for 1954–55 as follows:

Chairman—W. Brook Jones
1st Vice-Chairman—Maynard Hipwell
2nd Vice-Chairman—Frank Chandler
Secretary—Linwood B. Anderson
Treasurer—Robert M. Trombold
Chairman Membership Committee—George Watkins
Chairman, Program Committee—Maynard Hipwell
Technical Representative—Vaughan Calder, Jr.

Plant Tour

St. Louis, Mo.—The September meeting of the *St. Louis* Section was in the nature of a plant tour. This plant tour of Dow Chemical Co.'s Madison Magnesium Mill was of great interest to all those attending. Since rehabilitation of the Madison plant was started in January of 1951, equipment for rolling magnesium sheet and plate at a rate beyond all previous national capacity has been installed, and is in operation. Alloying and extrusion are also performed, the alloying operation being the first function of the new plant to be put into production.

The extrusion operations were very interesting, particularly the tremendous variety of shapes which can be so formed. Unlimited possibilities for extruded magnesium shapes can be visualized, particularly as production costs come down due to large-scale operations.

The main casting for a tremendous extrusion press was seen. Dow's literature, relative to this press, states: "In November of 1952, Dow signed a contract with the U. S. Air Force for the installation at Madison of a 13,200-ton extrusion press made by Hydraulik in Germany. This press, while partially completed when the contract was signed, was at such a state of development that certain modifications could be made to make this the largest, most modern press in the U. S."

All in all, this was a very interesting plant tour, particularly since it deals with such a revolutionary material, which is certain to become more prominent in the future.

Low-Hydrogen Electrodes

St. Louis, Mo.—The regular monthly dinner meeting of the *St. Louis* Section was held on October 14th at the Forest Park Hotel. The speaker was R. K. Lee AWS, of the Alloy Rods Co., York, Pa.

Mr. Lee's talk was very interesting and he explained how low-hydrogen electrodes function to eliminate underbead cracking in hardenable steel. He stated that the hydrogen in the welding atmosphere, from moisture present in ordinary rod coatings, is atomic and dissolves in the weld metal. As this metal cools, the solubility of the hydrogen atoms decreases immensely, and they tend to go out of solution. Some of these atoms accumulate in submicroscopic pores in the steel and unite to form molecular hydrogen, which cannot leave the solution. This molecular hydrogen builds up pressure within the structure of the steel. This pressure will not cause trouble in low-carbon steels, because they are very ductile and will yield. However, in hardenable steels, such as armor plate, the material has been hardened by the heat of welding, and is not ductile, and the pressure built up by this hydrogen will cause underbead cracking.

Mr. Lee explained how low-hydrogen electrodes eliminate this cracking and also how the addition of iron powder in the electrode coatings assists in this process. He claimed that iron powder in the low-hydrogen electrode will increase the adaptability of the electrodes, increase the speed of welding, increase the quality of the weld and improve the appearance of the weld.

Contact Electrodes

Sheffield, Ala.—The September 30th dinner meeting of the *Tri-Cities* Section was addressed by E. DiLiberti AWS, of the Air Reduction Sales Co., New York, on the subject "Contact Electrodes."

Tool and Die Welding

Sheffield, Ala.—"New Developments in Tool and Die Welding" was the subject of a talk given by L. D. Richardson AWS, of the Eutectic Welding Alloys Corp., at the October 28th meeting of the *Tri-Cities* Section. Mr. Richardson's talk was augmented with films and other visual educational materials.

Plant Visit

South Bend, Ind.—The *Michiana* Section held its second meeting of the season on October 21st at the Dodge Manufacturing Corp. plant in Mishawaka, Ind.

Leo T. Joyal AWS, gave a short talk on the history of the Dodge Manufacturing Corp. who were among the first manufacturers of power equipment in this part of the country. He also told about some of the products being manufactured at the present time, some of the methods used and the plant layout.

At the conclusion of Mr. Joyal's talk, the members toured the plant in groups, each with a representative from the plant who was very helpful in explaining the various things seen.

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"CS" Cutting Attachment
"5" Welding Torch
"45C" Welding Torch
"D" Cutting Torch
CM Cutting Torch
FOR OXY-ACETYLENE WELDING AND CUTTING
There is a Dockson Better-Built Torch for all your jobs. Dockson Torches incorporate a new, longer life, better seal compound developed especially for oxy-acetylene service in both the mixer and union rings. Dockson's two-ring construction means fewer rings to replace, stronger construction, prevention of possible back-through.
Your DOCKSON DISTRIBUTOR—a selected specialist, stocks a complete line of Dockson products to give you fast service and personal attention. We back our distributors 100%.
WRITE FOR YOUR DISTRIBUTOR'S NAME AND COMPLETE CATALOG OF WELDING AND CUTTING EQUIPMENT.
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3839 WABASH • DETROIT 8, MICH

Toledo Section Tour

After the two-hour trip, refreshments were provided by the company.

Electrode Coating

Springfield, Mass.—The October 5th dinner meeting of the *Western Massachusetts* Section was held at Blake's Restaurant in Springfield.

H. F. Reid, Jr. AWS, the McKay Co., Pittsburgh, Pa., gave a very interesting talk on the flux coating of electrodes explaining in detail why the coating was there, what its purpose is, and how it functions. He also explained the difference between coatings of all types of electrodes. The audience was very much interested in Mr. Reid's talk and the slides which he showed. The meeting was very successful.

Program of Meetings

Springfield, Mass.—Program of meetings for the remainder of the 1954-55 season of the *Western Massachusetts* Section is given below:

Jan. 11, 1955—Speaker: G. K. Willecke, Miller Electric Manufacturing Corp., Appleton, Wis. Subject: "A Rectifier Type D-C Arc Welder."

Feb. 8, 1955—Movies: Marquette Manufacturing Co., Inc., 307 E. Hennepin Ave., Minneapolis 4, Minn. Subject: "Marquette Goes to the Races—The Marquette Story." Nontechnical.

Mar. 8, 1955—Speaker: Sidney Low, Chapman Valve Manufacturing Co., Indian Orchard, Mass. Subject: "Nondestructive Testing in Welding." This is a Joint Meeting with Connecticut Valley Section of Non-Destructive Testing Society.

Apr. 12, 1955—Movies: Canadian Pacific Railway Co. 581 Fifth Ave., New York 17, N. Y. Subject: "Canadian Pattern, Canada's Tackle Busters."

Syracuse, N. Y.—The regular monthly meeting of the *Syracuse* Section was held at the Hotel Onondaga on Oct. 13, 1954.

The speaker at this meeting was Paul Thorne AWS, Chief Electrical Engineer of the National Electric Welding Machines Co., Bay City, Mich.

Mr. Thorne presented an interesting talk entitled "Automation in the Resistance Welding Industry."

In his discussion pertinent to the design of automatic resistance welding equipment, Mr. Thorne pointed out that there were a number of important factors which must be taken into consideration in the development of satisfactory equipment. Among these were:

1. Low-cost production.
2. Weld quality.
3. Limitations of primary current requirements.
4. Ability to stop and restart welding cycle, or to recycle completely, if necessary.
5. Safety, both as regards operator and equipment.

Mr. Thorne's talk was illustrated by an excellent group of slides showing various types of intricate automatic resistance welding equipment and a movie showing the operation of automatic equipment used in the manufacture of 55-gal steel drums.

The regular meeting was preceded by a dinner meeting highlighted by the presentation of a movie entitled "Modern Gem Cutting." This was a color film complete with sound showing equipment and techniques employed in gem cutting for the hobbyist. This picture was extremely interesting and it was well received.

Tour of Refinery

Toledo, Ohio.—The *Toledo* Section started the 1954-55 meeting season with an excellent tour of the multimillion-dollar Sun Oil Co. East Toledo refinery. Through the excellent cooperation of the Sun Oil Co. the members and guests of the Toledo Section were taken on a 2-hr tour of the refinery in groups of five people each, with a guide to explain the operation of the plant. Included in the tour was the Welding Shop, Boiler Shop, control rooms, hydrogen ovens and, to the delight of many of those present, an elevator trip to the top of the 365-ft catalytic cracking tower, the highest structure in the area. One point of the tour was the construction area where welding and fitting were in progress on Sun's new "cracking" unit, giving many of the guests a first-hand view of some of the more critical and tedious operations encountered in the construction of such an enormous structure. The meeting was preceded by dinner in the refinery cafeteria and a general briefing by refinery personnel pertaining to the refining process and exactly what the Toledo plant manufactures. Mr. C. E. Edwardson AWS, Chairman of the Toledo Section, wishes to pass on the gratitude of all those present who had a most enjoyable evening.

Inert Arc Spot Welding

Washington, D. C.—The September dinner meeting of the *Washington* Section was held on the 28th at Naylor's Restaurant. Through the courtesy of the Washington Gas Light Co. a film was shown entitled "Storage of Natural Gas Underground."

Technical speaker was C. A. McClean AWS, Air Reduction Sales Co., New York, who presented a semitechnical talk on "Aircospot Welding Processes and Applications."

Meeting Dates

Washington, D. C.—The meeting dates of the *Washington* Section for the remainder of the 1954-55 season are as follows: Jan. 25, 1955; Mar. 1, 1955; Mar. 29, 1955; Apr. 26, 1955. (Annual banquet meeting location will be announced later.)

"Preheat" with cocktails at 6 P.M. Dinner at 6:30, followed by a coffee talk. Technical session begins at 8:00.

Panel Discussion

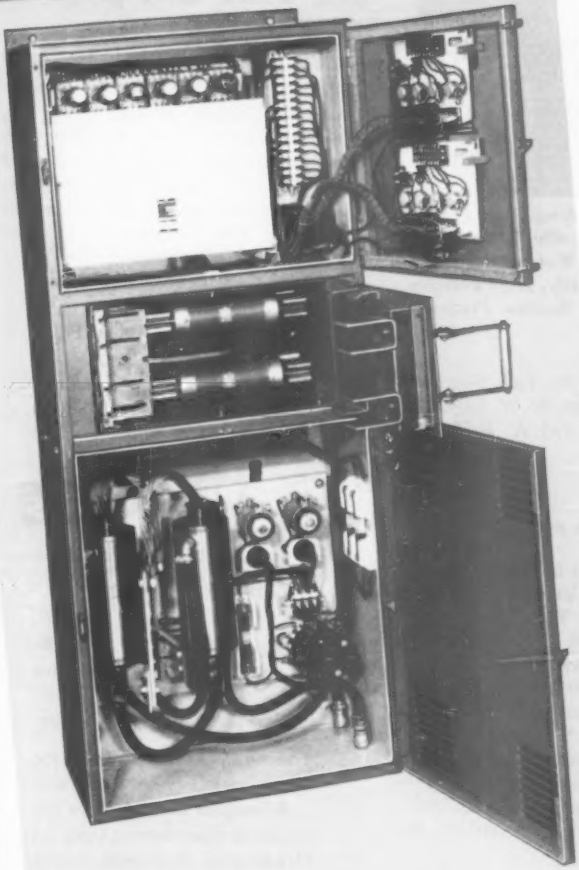
Washington, D. C.—A panel discussion on "Standardization of Building Codes in the Washington Metropolitan Area" was held by the *Washington* Section on October 26th at Naylor's Restaurant. The discussion was limited to welded structures and was very interesting and lively. Panel members were: D. Croy, Building Inspector, Fairfax County, Va.; A. Jensen, Chief Building Inspector, Arlington County, Va.; A. R. Lash, Building Inspector, Alexandria, Va.; J. B. Lauer, Chief Building Inspector, Prince Georges County, Md.; N. L. Roddy, Chief, Division of Building Inspection, Montgomery County, Md.; W. Steward, Engineer, District of Columbia; J. Hill, Moderator, Hill, Schrider & Kimmel Inc., General Contractors.

Informal Meeting

Worcester, Wass.—A "Duties of Officers and Directors" meeting of the *Worces-*

faster!

WELDING PRODUCTION ON REPEAT OPERATIONS



Square D's High-Speed Electronic Welder Control

faster! More spot welds per minute for repeat gun or machine welding operations . . . obtained by providing an additional SQUEEZE DELAY timing and a negative HOLD time sequence.

more consistent welds! Synchronized firing of ignitron tubes (welder transformer) and full cycle conduction provides uniform heat for each weld. Vastly improves quality of work.

less maintenance! Control unit uses heavy duty relays and components specifically designed for high speed welding service. Minimizes down time.

plus safety! Square D Fail-Safe tube circuits do not require conduction of an electronic tube to stop the weld . . . less possibility of danger to the operator and damage to the machinery.

dual **SEQUENCE ADJUSTMENTS** . . . provide complete control of two welding guns operated from one welder transformer and controller.

Write for High Speed Welder Control Bulletin #8992. Square D Company, 4041 North Richards Street, Milwaukee 12, Wisconsin.

SQUARE D COMPANY

Officers Attending October Meeting

York-Central Pennsylvania Section (left to right): William Delong, Vice-Chairman; David Walters; Earl Jennings, Section Secretary; Charles Allen, Treasurer; Roger Tuthill, Section Director and G-E Staff Member; A. V. Welch, Manager-Engineer, General Electric; Paul Stumpf, Chairman; W. W. Lilly, Jr., Publicity Chairman; C. E. Lewis Kerchner; "Tex" Leach, G-E Staff, Section Program Chairman

ter Section was held on Monday, October 4th, at the Tower House. Past-Chairman E. J. Adams, acquainted the members with the duties of the officers and directors, what their responsibilities are for the SOCIETY and the general operation from the local level. A short discussion followed on the plans for the coming year.

Board Meeting

York, Pa.—The first Board of Directors' Meeting of the *York-Central Pennsylvania* Section was held on September 1st, at which time plans were made for the coming fall and winter season. Shown on the photo reproduced herewith are: Frank A. Logue, Past-Chairman; C. E. Lewis Kerchner, Entertainment Chairman; Paul Stumpf, Chairman; and Charles W. Allen, Treasurer. Standing are: R. W. Tuthill, Program Chairman; G. Earl Jennings, Secretary; Philip Ruby, W. W. Lilly, Jr., Publicity Chairman, and A. F. Leach, Program Chairman.

Open House and Tour

York, Pa.—The first fall meeting of the season of the *York-Central Pennsylvania* Section was held on Thursday evening, October 21st, sparked by a guided tour through the newly established General Electric Welding Plant in York. Following the tour a brief business meeting was held, at which time C. I. McGuffie AWS Manager of Marketing for G-E, gave a 15-min Welcome Address and briefly outlined the staff operation and general facilities. Refreshments were served in the plant cafeteria.

AWS

National Spring Meeting
and
Welding Exposition

Kansas City, Mo.
June 7–10, 1955

Plan to attend

Employment Service Bulletin

Position Vacant

V-316. Excellent opportunity for ambitious, capable Welding Engineer, foreman or supervisor. National magazine published in Cleveland, Ohio, needs an Associate Editor with knowledge of welding processes, ability to write intelligent reports and average typing know-how. Good salary, pleasant working conditions, all employment benefits and interesting future. Send brief résumé of your educational, technical and/or practical experience.

Services Available

A-660. Works Manager—24 years diversified experience in metal fabrication covering production, qnality control and engineering. Heavy experience in welding, forming and allied operations, as well as purchasing, labor relations and product engineering. Will relocate.

persistent hoarseness or cough

...is one of the seven commonest danger signals that *may* mean cancer...but should *always* mean a visit to your doctor.

The other six danger signals are —Any sore that does not heal ...A lump or thickening in the breast or elsewhere...Unusual bleeding or discharge...Any change in a wart or mole... Persistent indigestion or difficulty in swallowing...Any change in normal bowel habits.

For other facts about cancer that may some day save your life, phone the American Cancer Society office nearest you, or write to "Cancer"—in care of your local Post Office.

American Cancer Society

LIST OF NEW MEMBERS

Effective September 30, 1954

Membership Classification

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

ANTHONY WAYNE
Jay, Glenn A. (B)

ARIZONA
Meehaw, Stephen A. (C)

BIRMINGHAM
Carlson, Enoch K., Jr. (C)

CHICAGO
Canonico, Domenic A. (C)
Carlson, Ray (B)
Hetfleisch, Anthony J. (C)
Kamarovsky, Serge (C)
Kelly, Claude E. (C)
Marshall, Richard H. (B)
Schroeder, Henry C. (B)

CINCINNATI
Meyer, Frank (C)
Yungbluth, Jack C. (C)

CLEVELAND
Lockhart, Dave L. (C)
Lowe, Charles M. (C)
Murbach, John R. (C)
Reed, David W., Sr. (C)
Snyder, Robert F. (C)

COLORADO
Leif, William G. (B)

COLUMBUS
Green, Joseph B., Jr. (C)
Merrill, Timothy W. (B)

DETROIT
Lenihan, J. P. (B)
Mainwaring, Joseph E. (B)
Miller, Jack M. (C)
Sutterfield, William L. (C)
Thompson, L. D. (C)

EAST TEXAS
Delk, Thomas D., Jr. (C)

FOX VALLEY
Comperini, Robert D. (C)
Hill, Raymond (C)
King, Robert (B)
Lange, Edward (C)
Miller, Robert (C)
Robinson, Arthur (C)
Roff, Leonard (B)
Saiberlich, Henry A. (B)
Skatrud, Harlan (C)
Van Ryzin, Howard (C)
Zimmerman, Wilmer M. (C)

HARTFORD
Brickett, James A., Jr. (C)
Mertz, Fred (C)

HOLSTON VALLEY
Abel, Fred (B)
Bailey, Paul J., Jr. (B)
Botts, J. G., Jr. (C)
Brandon, W. R. (B)
Campbell, Ed. N. (B)
Church, William Frank (B)
Clore, Glenn H. (C)
Collins, Luther C. (B)
Deakins, John H. (C)
Denny, John W. (B)
Durrett, J. R. (B)
Freeman, James L. (B)
Goodman, J. R. (C)
Griffin, Charles W. (C)
Hackley, J. E. (C)
Hall, R. B. (B)
Harr, Hugh, Jr. (C)
Haynes, T. A. (B)
Holloway, V. D. (C)
Hudson, Foster L. (B)
Hughs, Blaine (B)
Hurley, Chester A. (B)
Jacobs, S. L. (C)
Johnson, J. B. (B)
Jordan, O. C. (B)
Kerney, W. H. (C)
Lahr, Robert W. (B)
Markham, George Wells (B)
Mathews, W. E. (B)
McCormick, Richard D. (C)
Mullins, John P. (B)
Neal, Robert L. (C)
Newton, Charles (B)
Pyle, Carl E. (C)
Pyle, Scott (B)
Rogers, Jay C. (C)
Scott, L. T. (B)
Starnes, James H. (B)
Staten, Joe S. (B)
Stout, R. G. (C)
Tester, Benjamin S. (B)
Thomas, I. B. (B)
Tucker, Claude R. (B)
Tucker, William F. (B)
Vance, James H. (B)
Watson, Douglass R. (C)
Williams, John T. (B)
Young, E. B. (B)

HOUSTON
Kruemcke, M. R., Jr. (B)

IOWA
Dutton, Elmer E. (C)
Hutchison, Marion E. (D)
Peterson, E. J. (C)
Putnam, Wayne E. (B)

IOWA-ILLINOIS
Doyle, Howard E. (B)
Gustafson, A. R. (C)
Tindel, Chas E. (B)

KANSAS CITY
Cromb, A. H. (B)
Edgeworth, Donald M. (C)
Filby, Ellsworth F. (B)
Lane, J. E. (B)
Marks, C. V. (B)
Marsh, R. G. (B)
Neal, Jack (C)
Smith, Russell E. (B)

LONG ISLAND
Grenz, John J. (B)
Muller, Henry (B)
Shepard, Arthur P. (B)

LOS ANGELES
Amstead, John W. (C)
Ayers, Melvin E. (C)
Best, Vincent G. (C)
Dannenhold, Charles J. (C)
Henrichs, Paul H. (C)
Kunz, Earl L. (C)
Marr, James A. (C)
McClure, George E. (C)

MAHONING VALLEY
Shickley, Charles D. (C)
Simmers, Charles F. (B)

MICHIANA
Balaban, Milan George (B)
Brownell, Thomas M. (B)
Couts, Joseph J. (B)
Doolittle, Floyd H. (C)
Scholz, Edwin L. (C)
Sellenberg, J. R. (C)
Swanson, Arthur (B)

MILWAUKEE
Banta, Frederic L. (C)
Heller, Alfred E. (C)
Lindenlaub, Ernest W. (C)
Wheatley, Charles W. (B)

NEW JERSEY
Leaming, Robert R. (B)
McNally, James P. (C)
Zilm, James H. (C)

NEW ORLEANS
Ellis, Curtis Randolph (C)
Nordin, Robert W. (C)

NEW YORK
Brenner, Allen V. (B)
Christopher, Harold (B)
Ginsburg, Louis (C)
Zwick, William J. (C)

NIAGARA FRONTIER
Manno, Louis (C)

NORTH CENTRAL OHIO
Smith, Wilmer C., Jr. (B)

NORTHEAST TENNESSEE
Woods, D. D. (B)

NORTHWEST
Henning, Norman E. (B)
Hoium, Harold O. (B)
Kardong, William Henry (C)
Osburn, Earl S. (C)

NORTHWESTERN PENNSYLVANIA
Andrews, Harold L. (B)
Sousa, Anthony J. (C)

OKLAHOMA CITY
Jewell, J. D. (C)

PHILADELPHIA
Ahlman, Charles W. (B)
Clash, Frederick H., Jr. (B)
Griffiths, Thomas J. (B)
Reeves, Raymond L. (B)
Wagner, John C. (B)

PITTSBURGH
Martin, Herbert (B)

PORTLAND
Hitchman, Ernest (B)

PUGET SOUND
Lechner, Robert D. (C)
McCarthy, Wm. G. (B)
Telford, Ernest R. (C)

ROCHESTER
Braun, John Paul (C)
Huntington, LeRoy William (B)
Shane, Stephen (C)
Von Schlichten, Frederick E. (C)

SAGINAW VALLEY
Lane, Donald M. (D)

SAINT LOUIS
Andrews, David M. (B)
Morris, John K. (C)
Rebhan, Harvey Edward (C)

SALT LAKE CITY
Katsanevas, Andy (B)

SAN FRANCISCO
Bragg, Charles M. (C)
Herbeck, W. H. (C)
Kersten, Robert H. (B)

SUSQUEHANNA VALLEY
Kocsko, Michael, Jr. (B)

More than doubles welding speed

30 P&H TH-200 high-frequency machines make inert gas arc welding 2½ to 3 times faster than former gas welding at Republic Aviation Corporation

No replacement maintenance in three and a half years of two-shift operation

You don't have to take our word for the outstanding performance record of P&H Welders. The following statements are actual quotes from a certified report issued by the H. P. Gould Co. of Chicago, who made an impartial study of welding operations at Republic Aviation Corporation, Farmingdale, L. I., N. Y.

"In the building of faster and better aircraft, new developments in welding have played an important part and P&H high-frequency inert gas welding has proved that it can solve the problems of welding aluminum alloys.

"Three and a half years ago, Republic Aviation tested P&H TH-200 HF Inert Gas AC Arc Welders, and evaluated them against the existing equipment in the plant, as well as against outside competition.

"P&H welders of four different types are now used in four locations in the plant, for the welding of hundreds of different parts. In general, they are welding aluminum alloys from .032" thickness up to .250", and heat-resisting alloys from .010" up to a thickness of .093". For arc-welding alloy steels (4130, 4140, 8630, 8740, etc.), experience has proved P&H electrode AW-4 most satisfactory, and it is used exclusively.

"Republic Aviation welding engineers back up the claim of the makers that P&H welders require very little maintenance. The 30 high-frequency arc welders have had no replacement maintenance whatever in three and a half years of two-shift operation — and the operating cost of each P&H TH-200 HF Welder is only 40¢ per day."

Like Republic Aviation, whose studies show P&H inert gas arc welding to be 2½ to 3 times as fast as former gas welding, you, too, can enjoy the money-saving advantages of P&H Arc Welders with Dial-lectric Control. You, too, can get faster, better welds at lower cost.

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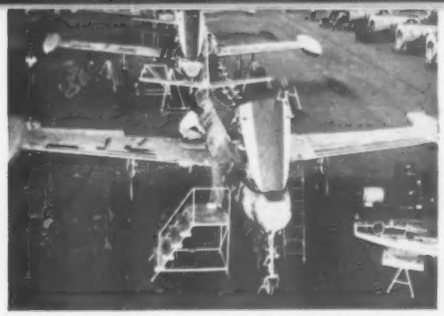
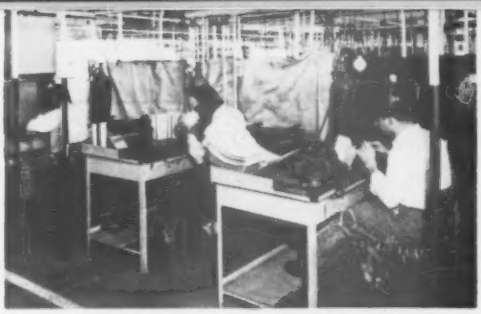


Going into Republic Aviation's "Thunderstreak" are the products and supplies of over 10,000 suppliers and subcontractors, many of whom take advantage of the same welding techniques used so effectively by Republic Aviation.



Republic Aviation meters welding current down to 5 amperes on the TH-200 HF welders. P&H's instantaneous heat control and built-in high-frequency feature permit easy regulation of high-frequency volume for individual jobs.

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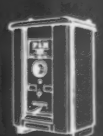

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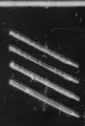

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abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

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2,690,493—Flux Supply System and Procedure—Walter S. Schaefer, East Gadsden, Ala., assignor to Republic Steel Corp., Cleveland, Ohio, a corporation of New Jersey.

This patent relates to a special flux supply system for welding apparatus wherein a storage tank discharges flux material to the work along the path of welding, and suction means are provided for applying suction to the work at a region along the welding path beyond the welding operation. Special separation means are provided in association with the suction apparatus to permit the larger particles of material drawn therein to settle in the tank while fine particles of the material are carried into a special section of the suction tank for storage therein and transmission to the flux storage container.

2,690,494—Spot Welding Method—Edmund S. Pomykala, Mobile, Ala.

This patent relates to the resistance welding of metal rods to a metal base plate and wherein a portable spot welder is provided that has a central positive electrode for being resiliently pressed against the rod to be welded and which also has a pair of negative electrodes mounted in spaced apart relationship on either side of the positive electrode. The negative electrodes are pressed against the base plate during the welding operation and the positive electrode is pressed against the rod in the immediate vicinity of a point where the rod contacts the plate. Next the negative electrodes are pressed against the base plate on either side of this point and a welding current is passed through the positive electrode, through the rod, through the contact between the rod and the plate, then through the plate to the negative electrode. The metal is fused at the contact points and welds the rod to the plate.

2,691,313—Adjustable Welding Horn Support— Merton E. Olson, Dyer, Ind.

Special adjustable welding horn supporting means are disclosed in this patent and include special rack and plate means positioned for fixed relative movement with relation to each other. A pair of control shafts are provided in the apparatus and releasable locking means are associated with each shaft for restraining movement thereof and corresponding movement of the apparatus controlled thereby.

2,691,691—Welding Cable Assembly—Frederick S. Wreford, Detroit Mich., Annie A. M. Wreford, executrix of the estate of Frederick S. Wreford, deceased.

Wreford's patent relates to a flexible cable unit wherein a tubular insulating casing is provided and a plurality of flexible welding current conductors are within the casing. A transversely extending insulating member is arranged lengthwise between the conductors while terminal heads connect to the opposite ends of the conductors. At least one of the terminal heads has a plurality of elongated terminals therein arranged side by side lengthwise of the conductors.

2,691,714—Welding Machine—Joseph A. Fotie, Kansas City, Mo., assignor to Rex Welder and Engineering Co., Kansas City, Mo., a corporation of Missouri.

This patent upon a welding machine covers apparatus including a wire feeding structure having an elongated, rotatable drum with a number of longitudinally extending wire receiving slots spaced around the periphery thereof. A number of spaced annular grooves intersect these slots, while a finger extends into each groove, respectively, for stripping the wires from the slots as the drum is rotated.

2,691,715—Arc Welder Control—Clifford T. Flora, Michigan City, Ind., assignor to Pullman-Standard Car Manufacturing Co., Chicago, Ill., a corporation of Delaware.

Flora's patent relates to means for controlling the rates of feed and travel relative to the work of the welding electrode in accordance with a characteristic of the welding current in an alternating-current arc-welding machine. A d-c feed motor is provided to drive the feed means in the apparatus and a d-c travel motor is provided to drive travel means in the apparatus with the speeds of the motors being substantially fixed relative to the welding current characteristic. Rectifier means connect to the alternating-current source and in the same phase as the electrode for deriving direct current from the alternating current supply and with the rectifier means also being connected to the motors to supply direct current thereto for actuation thereby. Thus variations in the value of the welding current characteristic due to fluctuations of the alternating current supply are simultaneously reflected in the direct current and thus in the motor speeds to maintain the desired relations therebetween.

2,691,952—Fusion Welding Backing Means—Evan F. Wilson, Akron, John C. Grubb Barberton, and Floyd A. Fowler, Toledo, Ohio, assignors

to the Babcock & Wilcox Co., Jersey City, N. J., a corporation of New Jersey.

In this patent, apparatus for backing a circumferential seam to be welded in the wall of a tubular body is disclosed. The apparatus comprises a plurality of plate-like guides arranged parallel to one another in relative slidable relationship longitudinally of their length. Other means cooperate with the guides to aid in positioning them in a desired "backing" position.

2,692,322—Induction Welding Method and Apparatus—Edward Bennett, Madison, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

Bennet's patent is on a method of butt seam welding the longitudinal edges of a tubular blank. By the method the longitudinal edges of the blank are positioned in opposed relation with a narrow gap therebetween and the edges are moved past a generally pancake-shaped induction heating coil disposed in contiguous straddling relation with the path of travel of the edges. Relatively high-frequency alternating current is applied to the heating coil to cause induction of currents flowing in opposite directions along the respective edge portions passing adjacent the coil and then the edges are converged into welding engagement at an apex disposed forwardly of the heating coil so that induced current flow around the apex is prevented and the proximity effect is utilized to cause concentration of the induced current into narrow bands along the edge portions with rapid heating of such edge portions to welding temperature.

2,692,323—Method of and Apparatus for Arc Welding—Karl Meller, Koin-Rath, Germany.

This patent relates to arc-welding apparatus including two welding current supply circuits having a common lead for connection to welding workpieces and having two other leads. A first electrode is placed upon a holding device on the work material at the seam to be welded and is connected to one of the supply circuits for maintaining a first welding arc. A manually operable electrode means connects to a second remaining lead for supply of welding current to provide a second welding arc adjacent to the first arc, while a relay device having normally open switch means is series connected in the one said supply circuit and has a control circuit connected with the other supply circuit for controlling the switch means to close such one supply circuit in response to the flow of current through the manually controllable arc.

2,692,324—Electrode Holder—Alex Strackbein, Edward S. Heck, and Arthur A. Henn, Milwaukee, Wis., assignors to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

The patented electrode holder includes a metallic conductor having a threaded portion at one end, and a hollow head of insulation material engages the threaded portion of the conductor. This head is adapted to position a welding electrode thereon. A metallic clamping block is disposed within the hollow head with the electrode being secured between the clamping block and the conductor as the head is advanced on the threaded portion of the conductor.

2,692,325—Portable Welding or Cutting Machine—Henry Jackson Stretton, Barnt Green, England, assignor to Fusarc Ltd., Gateshead-on-Tyne, England.

Stretton's patent is upon a portable machine for use in welding or flame-cutting operations on workpieces. A hollow body part is provided and has a handle by which the body part is manipulated by the user. A castor is mounted on the body part so that the machine can be supported on the workpiece and is movable therealong. A work-performing medium is positioned on the machine and the machine is adjustable so that the plane of the castor may be varied with respect to the axis of the work-performing medium.

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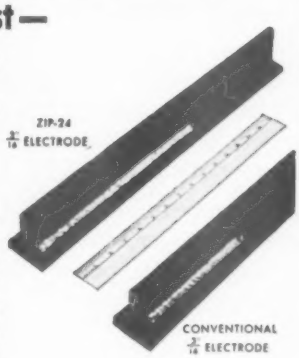

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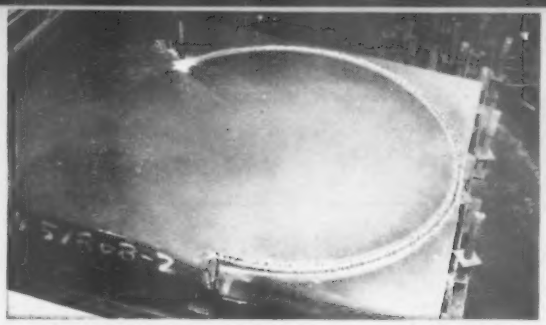

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Supplement to the Welding Journal, December 1954

Root Conditions in a V-Notch Charpy Impact Specimen

Strain conditions at the root of a Charpy-V notch specimen have been determined from a geometrically similar specimen large enough to measure the local strains

by H. A. Lequear and J. D. Lubahn

Abstract

The maximum conventional strain (in percent) at the root of a V-notch Charpy impact specimen is about ten times the angular displacement (in degrees) between the two ends of the bent specimen. The biaxiality at the notch bottom rises rapidly from zero at the side faces of the specimen and reaches 0.48 at the mid-width. Average strain at the notch bottom measured over a gage length equal to the root radius is within 10% of the maximum.

INTRODUCTION

THE problem of fracture in metals can be divided into two questions: (*a*) when does a crack begin? and (*b*) how does the crack propagate? In order to answer the first question, the state of strain at crack initiation, or "ductility," must be described. It is difficult to estimate the ductility at the bottom of a rather sharp notch, because the strain is highly localized. In a V-notch Charpy specimen, for example, where the root radius is only 10 mils, the largest strains are presumably restricted to a region of the order of 10 mils in width. It has been assumed[1] that this local strain is much larger than in a similar specimen without a notch, but how much larger this strain might be is not known.

H. A. Lequear and J. D. Lubahn are with the General Electric Co., Metallurgy Research Department, Schenectady, N. Y.

The Law of Similitude[2] offers a possibility of arriving at the local strain at the bottom of a notch. This law states that geometrically similar specimens loaded at similar points by loads proportional to the square of the dimensions will deform into geometrically similar shapes, and therefore will have identical states of stress and strain. Specifically for notched-bend specimens,

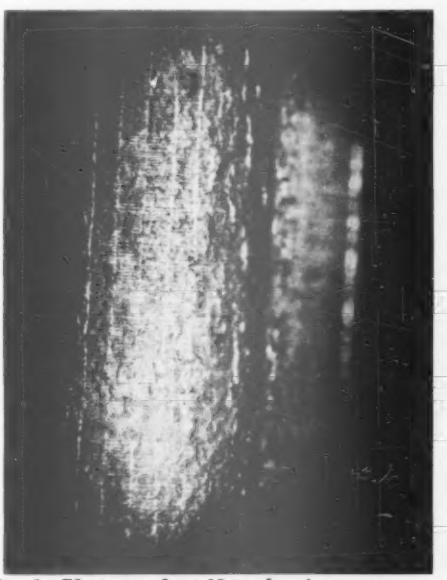


Fig. 1 Photograph at 10 × showing appearance of scribed lines on notch bottom of mild steel specimen after some strain

if one specimen were twice the size of another in all dimensions and were loaded with four times the load on twice the span, the local strains at the notch bottom would be equal for the two specimens when the bend angles were equal. Thus, if one measured the bend angle for a small specimen, such as a standard V-notch Charpy impact specimen, the local strain could be determined directly from a curve of bend angle versus local strain determined from a geometrically similar specimen large enough to measure the local strains. In the investigation described below, the object was to determine this strain-bend angle curve. In these tests, a longer bending span was used than that dictated by geometrical similitude with conditions in a standard Charpy test, in order to keep the bending force within reasonable limits. Although this deviation from similitude would have a large effect on the forces involved, it probably has little effect on the relation between two geometrical effects, such as bend angle and local strain. However, to be strictly correct, the strain-bend angle curve should be applied only to notched-bend specimens tested on the longer span that does represent similitude.

Preparation of Specimens

Specimens were machined from a 5-in.-round annealed brass bar, a 4-in. hot-rolled mild steel plate and a 4-in.-square hot-forged 28 aluminum bar. The specimens were made geometrically similar to a standard Charpy impact specimen, all dimensions being 8.9 times the standard dimensions. The bottom radius of the notch was lapped by rotation of a 0.182-in.diam-

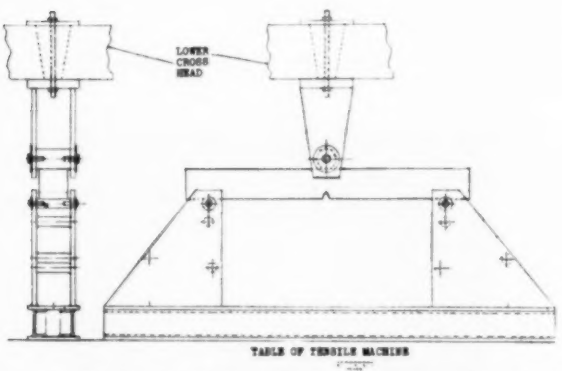


Fig. 2 Bending fixtures for large bend specimens

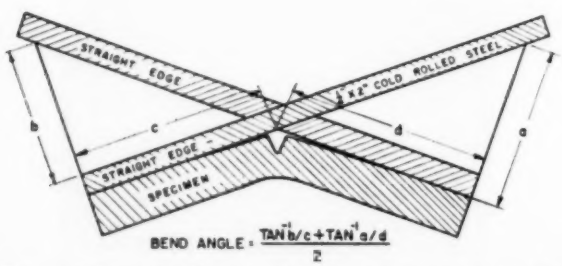


Fig. 3 Schematic diagram showing the measurement of bend angle

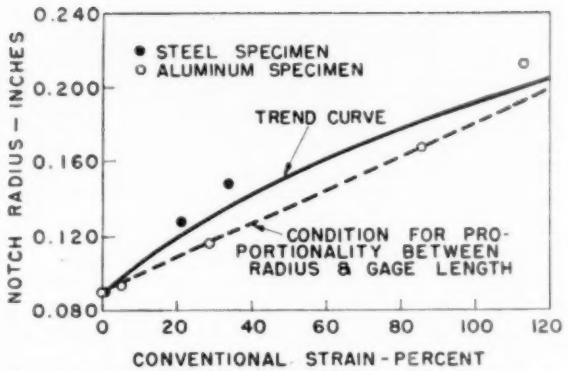
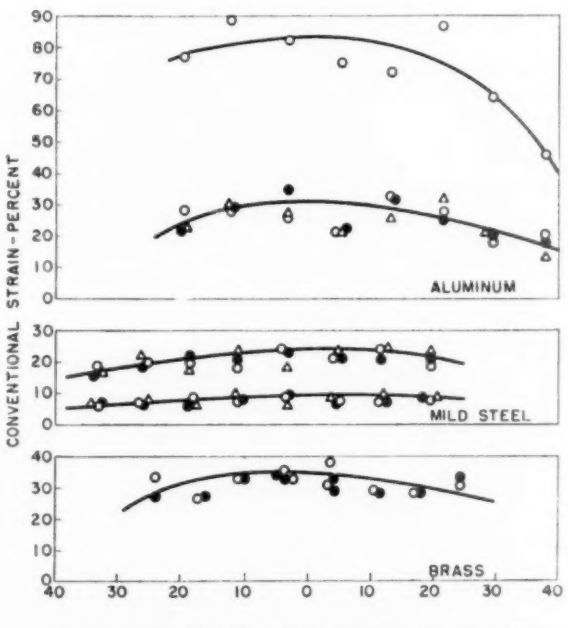


Fig. 4 Increase of root radius of notch with progressive bending

rod about its axis. On this lapped surface, 9 lines were scribed the length of the notch and about 10–12 mils apart. Figure 1 shows the appearance of these lines after considerable strain has rumpled the surface. Thus, four 10-mil gage lengths end-to-end on each side on the centerline were provided. The width of the scratches was adjusted to about 1 or 2 mils by regulating the distance that the point of the scriber stuck out of the rod in which it was mounted. The distance between lines was controlled by indexing the mounting rod for the scriber in a milling machine. Initially the average gage length intercepted an angle of 7.4 deg. Thus, the last line was about 30 deg up the radius from the bottom, as compared with 67 deg to the tangent point between the fillet radius and the straight side of the notch.


CONVENTIONAL STRAIN - PERCENT
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ANGLE FROM BOTTOM DEAD CENTER TO MID-POINT OF GAGE LENGTH - DEGREES

Fig. 5 Typical distributions of circumferential strain along the circumference of the notch bottom. Various kinds of points refer to different places along the length of the notch. Abscissa refers to initial angles, but angle did not change much (See Fig. 4)

Measurement of the Local Strains and Bend Angle

The bending was done in a tensile testing machine using the fixtures shown in Fig. 2. The span was 1.92 times that required for similitude. After each bending, the permanent bend angle was determined, as shown in Fig. 3.

For each angle of bend, every gage length was measured five times at each of three positions along the length of the notch. A toolmaker's microscope with a magnification of about 20 × was used. The table of the microscope was adjustable with a micrometer screw whose approximately 1-mm. divisions equaled 0.0001 in. The microscope tube was tilted with respect to the specimen to within 4 deg of the normal to the chord of the gage length being measured. This alignment insured less than about 0.2% error due to orientation effects. The proper angle was determined from rough measurements of the gage lengths and from the radius at the bottom of the notch. This radius was measured with a 61 × optical comparator by matching circles of known diameter to the shadow profile. The fillet at the bottom of the notch remained circular throughout the bending, as nearly as can be ascertained by matching circles. Figure 4 shows the observed variation of notch radius with local strain.

At very large strains the notch developed a noticeable curvature along its length (about $^1/_{16}$ in. deeper at mid-length than at the ends for 100% strain) so that the notch radius at mid-length was probably somewhat larger than at the side faces of the specimen, where the radius was measured.

Results

Figure 5 shows some typical strain distributions. The scattering about the trend line increases with strain, because the gage lines became somewhat less

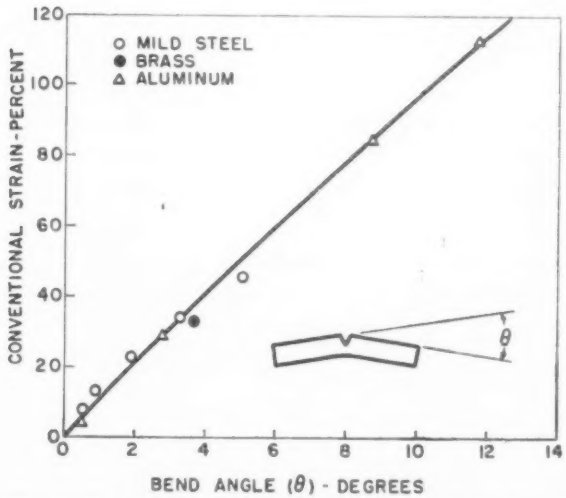

Fig. 6 Variation with progressive bending of maximum local strain at notch bottom of specimens geometrically similar (8.9 times standard size) to V-notch Charpy impact specimen. Span equals 7.7 times depth

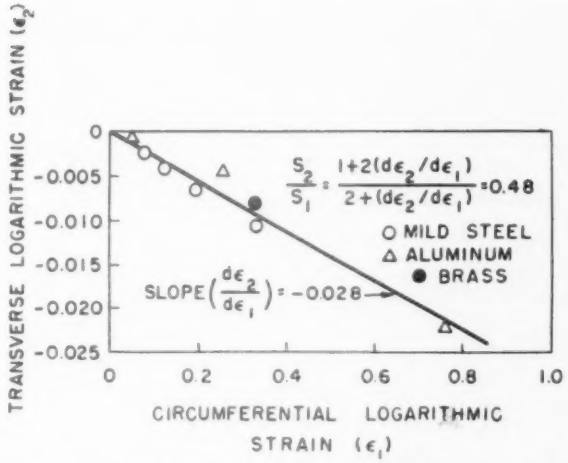

Fig. 7 Principal strains near mid-length of notch. "Transverse" refers to direction along the length of the notch

clear and harder to measure accurately. Within the limits of the scattering, the circumferential strain distribution was the same at points $^1/_2$ in. each way along the notch from the mid-length as the strain distribution at the mid-length. The circumferential strain was surprisingly uniform, considering that strain measurements were made as far as 30 deg up from the bottom of the notch. If one used a gage length equal to the root radius, the average strain over this length would be only 10% less than the maximum (see Fig. 5).

Figure 6 shows the maximum local strain as a function of bend angle for all specimens. Except for the last measurement on the steel specimen, the points for the different metals agree quite well. The last point for the steel specimen may have a ficticiously high bend angle because of the opening up of small cracks above the last gage length on the radius. The local conventional* strain is nearly proportional to the bend angle—roughly 10% strain per degree of bend angle. This is a somewhat greater strain concentration than the 3.5–5% per degree observed in a shallower groove used for testing welds.[3]

Biaxiality

The transverse strains were measured over $^1/_2$-in. gage lengths extending each way from the mid-length of the notch. Although the absolute values of transverse strains were at least 10 times more accurate than the circumferential strains, because of the longer gage length, the scattering of the values (Fig. 7) is still high because of the very small value of the transverse strains. Figure 7 shows that the transverse contraction is roughly 3% of the circumferential extension. The biaxiality can be determined using the Von Mises condition

$$\frac{S_1 - S_2}{d\epsilon_1 - d\epsilon_2} = \frac{S_2 - S_3}{d\epsilon_2 - d\epsilon_3} = \frac{S_1 - S_2}{d\epsilon_1 - d\epsilon_3} \qquad (1)$$

* Conventional strain equals [(final length/init. length) − 1], while natural strain (ϵ) is defined as $\log_e$ (final length/init. length).

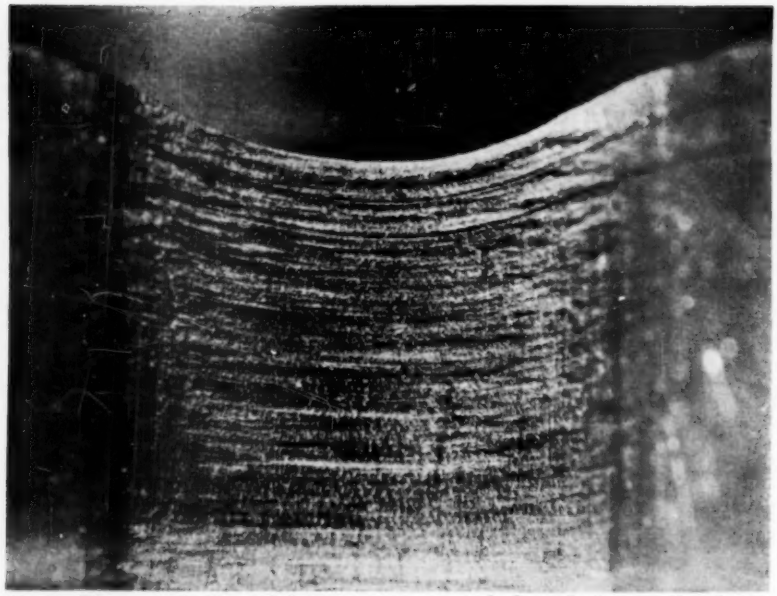

Fig. 8 Photograph of notch bottom near one end of notch showing "sucking-in" effect due to lack of complete transverse restraint. (Aluminum specimen)

and the constant volume condition

$$d\epsilon_1 + d\epsilon_2 + d\epsilon_3 = 0 \qquad (2)$$

Combining eqs 1 and 2 and noting that $S_3 = 0$,

$$S_2/S_1 = \frac{1 + 2(d\epsilon_2/d\epsilon_1)}{2 + (d\epsilon_2/d\epsilon_1)} \qquad (3)$$

The slope of the line in Fig. 7 corresponds to a biaxiality of 0.48, or very nearly complete transverse restraint near the mid-length of the notch.

Near the ends of the notch the metal had much more freedom to contract transversely, as shown in Fig. 8. This "sucking-in" effect caused a visible dimple on each side face of the specimen just below the notch bottom. In order to estimate the transverse strain in this area, circumferential lines were scribed in the notch of the aluminum specimen about 25 and 55 mils in from each side face of the specimen (see Fig. 8). Strain measurements (Fig. 9) on the 30-mil gage lengths between these two pairs of marks show that there is considerable transverse restraint even at points much nearer the side face of the specimen (40 mils to mid-gage-length) than the magnitude of the notch radius (about 90 mils). The observed strain ratio of -0.27 corresponds to a biaxiality of 0.27 according to eq 3, or more than half the biaxiality at the mid-length of the notch.

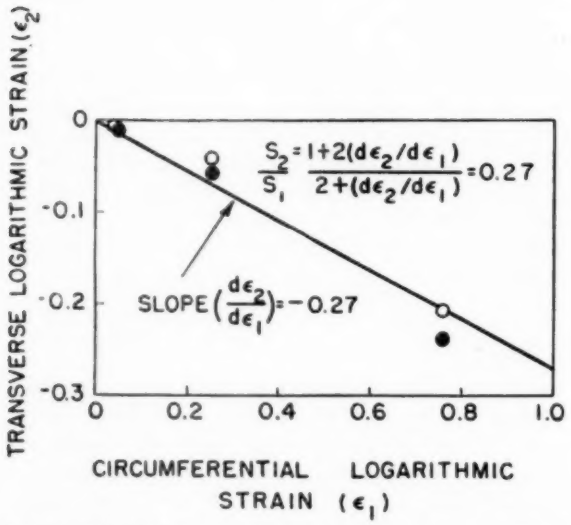

Fig. 9 Principal strains near ends of notch in aluminum specimen. "Transverse" refers to direction along the length of the notch. Different kinds of points refer to the two ends of the notch

In closing, a word should be said about the implications of the results. The "calibration" of bend angle against the local strain at the root of the notch would be very useful if it could be applied to small specimens, such as the standard V-notch Charpy bar, where local strain cannot be measured directly. The applicability to small specimens depends, however, on the validity of the "law of similitude" for plastic flow. Sachs[2] states that "no exceptions to this rule are known;" on the other hand, there is little experimental evidence specifically showing the validity of the law of similitude, and it might be well to bear this fact in mind when applying the above calibration of local strains to small specimens.

ACKNOWLEDGMENT

The author is indebted to J. F. Baxter for producing the scribed lines from which the measurements were made.

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Residual Stress and the Compressive Strength of Steel*

Final report on a pilot investigation to determine effects of residual stresses on compression members of structural steel

by A. W. Huber and L. S. Beedle

I. Synopsis

The scope of the investigation upon which this report is based was to determine whether residual stresses set up during cooling appreciably reduce the strength of compression members of structural steel and, if so, to find methods for predicting this reduction with satisfactory engineering accuracy.

The report shows that the strength of axially loaded columns of 8 WF 31 shape cannot be determined from results of small coupon tests but that due consideration must be given to residual stresses. The theories described give adequate explanation of experimental behavior. Data on the compressive properties of steel are also reported.

II. INTRODUCTION

IN ARRIVING at column formulas for specifications, the theoretical computations have been correlated with column test results. In more recent years, the stress-strain curve has figured prominently in analyzing the results of column tests.[6] Such curves have been determined from coupons cut from the cross sections of rolled shapes. In cutting these coupons, residual stresses (sometimes called "locked up" or "initial" stresses) have been released so that the measured stress-strain curves have necessarily omitted any possible influence of residual stress.

The strength of axially loaded columns free from residual stresses is given by the tangent modulus theory.[18] To apply the theory it is only necessary to have information on the compressive stress-strain relation in order to obtain the complete "column curve" of stress plotted against slenderness ratio. As numerous tests have shown,† this procedure permits the prediction of column strength for annealed material. Differences between theory and experiment can be attributed to such causes as initial curvature and eccentricity and both can be kept small in carefully conducted laboratory tests.

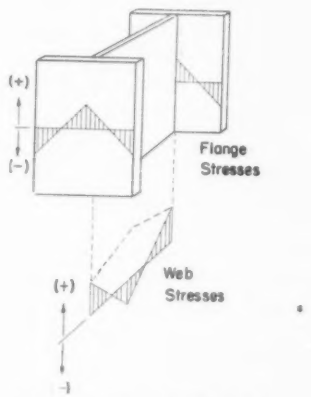

Fig. 1 Typical residual stresses in WF shape

When small coupons are tested in compression the resulting stress-strain diagram approaches an idealized curve consisting of two straight lines, one at a slope equal to the elastic modulus E, the other line being horizontal at the yield stress level (average stress in the plastic range). With such a curve it would seem that the tangent modulus theory was of little value in the case of structural steel. A consideration of residual stresses, however, shows its applicability.

1. The Nature of Residual Stress

Residual stresses are those that are left in a member after it has been formed into a finished product. In structural steel, residual stress may be due to several causes:

(*a*) Uneven cooling of shapes immediately after hot rolling.

(*b*) Fabrication operations such as cold-bending ("gagging"), punching, shearing, cambering and welding.

Only the first type (cooling residual stress) is considered in this paper.

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* This work has been carried out as part of an investigation sponsored jointly by the Column Research Council, the Pennsylvania Department of Highways and the Bureau of Public Roads.

† See p. 20 of Reference 6.

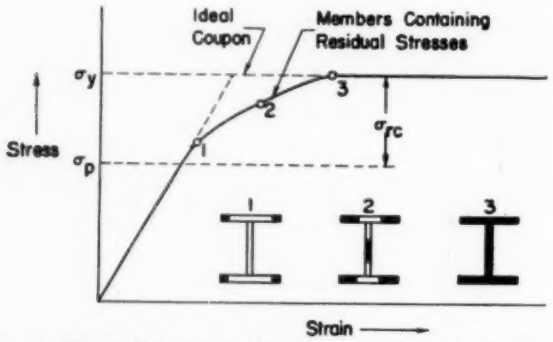


Fig. 2 Typical influence of residual stress on the average stress-strain curve

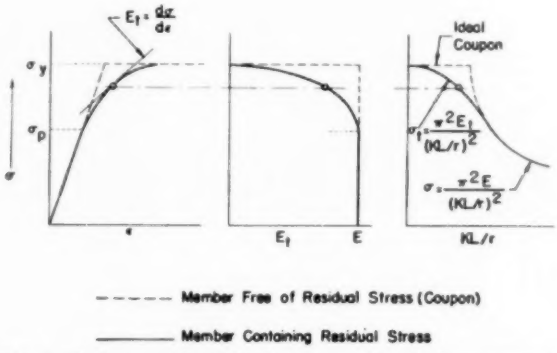


Fig. 3 Influence of residual stress on the "column curve"

The mechanism for the formation of cooling residual stresses has already been described. [4, 17, 19] The flange tips (which cool the most rapidly) are left in compression while the flange center is left in tension. As a general rule, the part of the member cooling most slowly will be left in residual tension. Figure 1 indicates a typical shape of residual stress pattern.

At Lehigh attention was first drawn to the importance of residual stresses by the results of box girder buckling tests.[12] It was also observed in tests on WF sections that yielding in the flanges of WF sections started at lower loads than theoretically predicted; therefore measurements of residual stresses were made.[11] These measurements and later experimental work on beams of WF shapes[19] confirmed beyond doubt the presence of residual stress. Magnitudes of compressive residual stress up to 20,000 psi have been observed in as-delivered rolled steel beams.[13]

2. *Influence of Residual Stress*

From the nature of residual stresses it can be seen that their presence has a definite influence upon the over-all stress-strain relation of structural steel. By partial yielding of a cross section under an applied uniform stress below the "nominal" yield point, increased strains result in the remaining elastic parts of the cross section, thus making the stress-strain relationship of the section nonlinear. Assuming the applicability of the tangent-modulus concept there will be a consequent influence of residual stress upon column strength.

The influence of residual stresses on bending members and on columns has been briefly described in References 9 and 12 and more extensively in Reference 19. In brief, referring to Fig. 2, if a compressive residual stress of magnitude σ_{rc} were present at the flange tips, then yielding would commence when $\sigma_p = \sigma_y - \sigma_{rc}$. The over-all stress-strain relationship for a column would thereafter be nonlinear; but with sufficient straining the average stress would reach yield-point magnitude.

Thus, the influence of residual stress in columns is to make the stress-strain relationship nonlinear above a residual-proportional limit, σ_p. Assuming the applicability of the tangent-modulus concept, there will be a consequent influence on column strength. This is illustrated in Fig. 3, the right-hand sketch being the familiar column curve.

Why aren't these stresses wiped out when the member yields? They *are* wiped out, but it is a gradual process, commencing at the stress, σ_p. As stress is increased, more and more of this stress is relaxed by plastic deformation until, at Point *3*, Fig. 2, the member is completely plastic and the stress is at yield-point level, σ_y.

One important conclusion from an earlier investigation[12] was the following:

"In welding thin plates it is necessary to keep the heat at a minimum, for otherwise the plates may buckle without the application of external load. It follows then, that the welding process may leave internal stresses which are not large enough themselves to cause buckling, but which will cause an apparent low buckling stress, when the girder is loaded. Whether the internal weld stresses will contribute to buckling or not will depend on the location and size of the welds. In a box girder, the tension due to the welds in the corners of the box cause compression stresses in all four plates, since the sum of the internal stresses must equal 0 for equilibrium. These stresses will lower the buckling values of the compression flanges and web plates."

Prior to the study now being reported a few isolated tests on as-delivered column also indicated that the strength was lower than predicted on the basis of small coupons cut from the cross section and this reduction could not be attributed entirely to such causes as initial curvature and eccentricity.

Therefore it is necessary to develop methods for predicting the strength of columns containing residual stresses and to examine current specifications and formulas to determine whether present design rules require modification either for safety or economy. These considerations led to the program here reported.

3. *Approach to the Problem*

As reported by Salmon[15] in 1921, as early as 1888 it was recognized that "previous strains" were of direct influence upon the strength of columns. Although other sources of "initial stresses" were mentioned, stresses set up due to cooling after rolling were not dis-

cussed by Salmon. He notes that "Considère suggested using test pieces that had undergone exactly the same processes as the member itself"—and this was one approach used in the investigation reported in this paper.

Recognition of the role of residual stresses is a contribution of the Column Research Council[8] which organization was established in an effort to remove the confusion and lack of harmony in column formulas in many specifications now in use.

Research carried out at the University of Illinois on the influence of welding residual stresses was reported upon in 1935.[18] Cooling stresses were not studied in that investigation which involved the study of built-up members. More recently studies have been conducted on model members with artificially induced residual stresses. Test results were reported* which show a substantial reduction in strength attributable to residual stresses. Recently Osgood[14] has discussed the general problem of residual stresses in columns. At Lehigh the problem has been investigated for steel columns.[19] Based on those investigations this paper outlines two approaches for a solution of the problem and its application to WF structural steel columns. The agreement between the two methods is very close and in addition is corroborated for 8 WF 31 sections by column tests.

The first method of approach to the problem is an analytical solution requiring (1) a knowledge of residual stress distribution (measured or assumed) and (2) the material properties (modulus of elasticity, yield stress level). As shown by the Lehigh study[19] the strength of the column can then be expressed as a function of the moment of inertia of the unyielded portion of the cross section (elastic moment of inertia, I_e) and the slenderness ratio.

The second method involves an analytical solution and requires only one measurement: the average stress-strain relation determined from a short member of sufficient length to retain the original magnitude of residual stresses. This is called the "cross-section" test since it involves testing the complete cross section of the specimen. Column strength can be expressed as a function of the tangent modulus obtained from the stress-strain curve of the "cross-section specimen" and the slenderness ratio with due allowance for bending about the strong or weak axis. This second method does not require the special measurement of residual stresses.

Both methods are limited in application to symmetrical residual stress patterns.

4. *Compressive Strength of Steel*

Up to this point attention has been directed to the influence of residual stresses. Of considerable additional importance is the basic strength of steel in compression, or more particularly the yield stress level, σ_y (Fig. 3). A few careful studies have been made of the strength of steel in compression and in one,[7] comparison was made with results of tension tests.

Compression testing is considerably more difficult to accomplish than tension testing, and correlation between the two is essential if the results of tensile tests are to be the basis for predicting the strength of axially loaded columns.

In an acceptance test performed according to the ASTM standards, the specimen is usually selected from the web and is tested in tension. This material usually has a higher yield stress than the flange material, and represents about 25% of the load capacity of typical rolled column sections. Therefore, a true interpretation of the strength of an axially loaded column requires a consideration of the difference in material properties across the section.

Careful machining is required of compression test coupons and usually a number of specimens are required from one cross section before a good average may be made. Thus the "cross-section" test previously mentioned offers possibilities of an economical substitute for a large number of coupon tests.

Answers to the following questions are then desired:

(*a*) What is the strength of full cross sections of the various rolled shapes (WF, angle, channel) and how do their properties compare with those given by coupon tests?

(*b*) How do the compressive properties so determined compare with the ASTM-type tension tests of specimens cut from the web? Can a correlation be established that will be useful in arriving at compressive strengths of structural shapes?

The answers to these questions will be sought in future investigations. Exploratory relationships may be seen in the data presented herein.

* * *

The study was limited to ASTM Grade A-7 steel rolled to 8 WF 31 shape. This is one of the most frequently used shapes for building columns and although it is expected that the results described will be similar for other rolled column shapes, quantitative applicability to such shapes remain to be confirmed experimentally in a general investigation now in progress.

It is the purpose of this paper to describe theoretically the influence of residual stress, present test results in substantiation of the theory, give data on compressive properties of steel, and to examine approximate formulas for the maximum strength of axially loaded columns.

III. THEORETICAL ANALYSIS

The ideas presented in earlier investigations[14, 19] are extended here for practical application to WF sections. The subsequent derivations are made under the following assumptions:

1. The stress-strain behavior of fibers of the mate-

* Cherry, S., Chow, P. Y., and Austin, W. J., "Experimental Studies of Model Columns," Structural Research Series No. 34, University of Illinois (July 1952).

Fig. 4 Partially yielded cross section

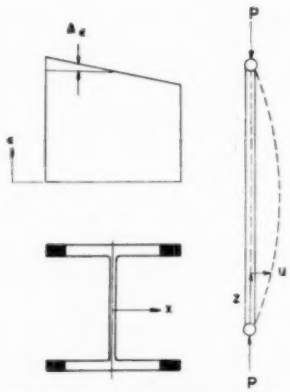


Fig. 5 Partially yielded column in the bent position

rial is characterized by two straight lines of slopes E and zero (ideal stress-strain diagram for steel).

2. Plane sections remain plane after deformation.

3. The residual stress distribution is symmetrical with respect to both axes of the WF sections; the residual stresses are constant along the column.

The derivations are divided into two parts: (1) those based on measured or assumed residual stress patterns and (2) those based on the "cross-section" test. For completeness some of the material presented elsewhere is repeated here.

1. *Rectangular Shape—Known Residual Stress*

When a steel column is strained above the residual-proportional limit, portions of the cross-section yield (Point *1* of Fig. 2) If the yielded parts are perfectly plastic, the bending stiffness of those parts reduces to zero. The theoretical buckling strength will then be equivalent to that of a new column whose moment of inertia, I_e, is the moment of inertia of the remaining elastic cross section,[19] or

$$P_{cr} = \frac{\pi^2 E I_e}{L^2}$$

or

$$P_{cr}/A = \frac{\pi^2 E (I_e/I)}{(L/r)^2} \qquad (1)$$

The action of a rectangular specimen is described in Appendix 2 and it is shown there how the column curve may be obtained for particular residual stress distributions.

2. *WF Shape Consisting of Two Rectangles—Known Residual Stress*

If the web is neglected and if it is assumed that a WF shape consists of two equivalent rectangles, then, referring to Fig. 4,

$$\left.\frac{I_e}{I}\right|_x = k \text{ (flexure about } x\text{-}x \text{ axis)}$$

$$\left.\frac{I_e}{I}\right|_y = k^3 \text{ (flexure about } y\text{-}y \text{ axis)}$$

in which $k = [x_0/(b/2)]$. The above equation is an approximation that neglects the moment of inertia of the rectangles about their own axes. Equations for the critical slenderness ratio are the same as in Appendix 2; the weak axis of the rectangle is the strong (x-x) axis of the WF shape.

3. *WF Shapes—"Exact" Solution for Known Residual Stress*

The previous solutions have all assumed that the web of a WF shape contains no residual stress. Numerous measurements have been made indicating that this is not the case.

A solution based on coupon test results and a known residual stress pattern which takes into account the web residuals and is applicable to WF shapes may be obtained using the approaches previously mentioned.

Considering the column in Fig. 5 the strain ϵ will increase uniformly until bending starts (corresponding to the tangent modulus load of the Engesser-Shanley theory). Then the following equilibrium equation for the infinitesimal bent position about the y-axis results:

$$Pu + \int_A E(x)(\Delta\epsilon)(x)\, dA = 0$$

From the relationship $\Delta\epsilon/x = d^2u/dz^2$ there is obtained

$$Pu + \frac{d^2u}{dz^2} \int_A E(x) x^2\, dA = 0 \qquad (2)$$

which corresponds to the Euler differential equation for E = constant.

The integral in eq 2 is readily evaluated for the "ideal" stress-strain curve of structural steel.

$$\int_A E(x) x^2\, dA = E \int_{A_e} x^2\, dA = E I_e$$

I_e is the moment of inertia of the elastic part of the cross section.

The critical stress, i.e., the stress at which the column may start to bend, can therefore be written in the form

$$P_{cr}/A = \sigma_{cr} = \pi^2 \frac{E I_e/I}{(L/r)^2} \qquad (1)$$

For the solution of eq 1 the relation between σ_{cr} and I_e must be known. This may be found by obtaining an expression for σ_{cr} in terms of the yield condition (x_0) and by obtaining an expression for I_e in terms of the geometry at the yield condition. This has been done in Appendix 3. Two cases have been considered:

(a) Yielding does not commence in the web until the flanges are fully plastic.

(b) The web starts to yield before the flanges have completely yielded.

If the tensile stress at any point in the web is less than that in the flange, then Case (b) is applicable.

In Figs. 39 and 41 typical stress-strain curves have been drawn and the applicable equations are tabulated there.

A sample solution has been carried out in Appendix 4.

In the previous three sections it was assumed that the yield stress level and the residual stress distribution were known. Using the same original assumptions the problem can be approached in a different manner, based on application of tangent modulus theory to a "cross-section" test.

4. *"Cross-Section" Analysis—Rectangular Specimen*

Suppose a rectangular specimen containing residual stress and short enough to prevent failure as a column were loaded in compression. Now,[19]

$$E_t = \frac{d\sigma}{d\epsilon} = A_e E/A$$

In a rectangular element bent about its weak axis, $I_e/I = A_e/A$. For flexure about the strong (y-y) axis,

$$I_e/I = (A_e/A)^3$$

Since

$$E_t/E = A_e/A = k$$

then eq 1 becomes, for the two flexure axes:

$$\sigma_{cr} = \frac{\pi^2 E_t}{(L/r)^2} \qquad \text{(axis } x\text{-}x\text{)} \qquad (3)$$

$$\sigma_{cr} = \frac{\pi^2 E(E_t/E)^3}{(L/r)^2} \qquad \text{(axis } y\text{-}y\text{)} \qquad (4)$$

The values for E_t are determined from the test of the full rectangular cross section. Since $E_t/E = k$, this approach should give the same result as that in Section 1, previously.

5. *Cross-Section Analysis—WF Shape (Approximation)*

A demonstration that tangent-modulus theory is applicable to the cross-section test of a WF shape may be seen from the following which is based on a suggestion made by B. G. Johnston. It is assumed that the residual stress distribution is such that the flange is fully plastic before the web yields. Using $E_t/E = A_e/A$, in which $A = A_w + A_F$; $A_e = A_w + kA_F$; and where $k = x_0/b/2$ as before, then $E_tA = E(A_w + kA_F)$ and solving for k as a function of E_t,

$$k = \left[\frac{AE_t}{A_F E} - \frac{A_w}{A_F}\right] \qquad (5)$$

Now approximately, neglecting the moment of inertia of the web about its own axis, $I_{cx}/I_y = k^3$. Then, for the weak axis

$$\sigma_{cr} = \pi^2 E k^3/(L/r)^2 \qquad (6)$$

where k is computed by eq 5.

For flexure about the strong axis, neglecting the moment of inertia of the web $I_{cy}/I_x = k$. Then, from eq 1,

$$\sigma_{cr} = \frac{\pi^2 E k}{(L/r)^2} \qquad (7)$$

where k is given by eq 5.

The slenderness ratio, L/r, for critical stress at a given E_t may then be computed.

k in eq 5 may be expressed approximately as $k \doteq E_t/E$. Equation 7 then becomes

$$\sigma_{cr} = \frac{\pi^2 E_t}{(L/r)^2} \qquad (8)$$

6. *Cross-Section Test—"Exact" Solution, WF Shape*

Assume a WF-section subjected to compression, the length being sufficiently small to prevent failure as a column. If no residual stresses were present the stress-strain curve would be linear up to the yield stress level. Due to residual stresses, the curve would deviate from the slope E at a stress $\sigma_p = \sigma_y - \sigma_{rc}$ (proportional limit for the cross-section test). Above the proportional limit (see Appendix 3, eq 14) the strain is given by

$$\epsilon = (1/E)(\sigma_y - \sigma_{rx_0})$$

for yielding in the flanges only. After the flanges have become completely plastic similar expressions for strains at subsequent stages may be obtained and are tabulated in Figs. 39 and 41. The average stress is given by eq 16 (see Appendix 3)

$$\sigma_1 = \sigma_y - \frac{A_e}{A}\sigma_{rx_0} - \frac{4t}{A}\int_{x_0}^{b/2} \sigma_{rx}\, dx$$

Using eqs 14 and 16 the average stress-strain curve of the cross section can be computed. The tangent modulus of the curve is given by

$$E_t = \frac{d\sigma}{d\epsilon} = \frac{d\sigma}{dx_0}\frac{dx_0}{d\epsilon}$$

By differentiating eq 16

$$\frac{d\sigma}{dx_0} = \frac{1}{A}(4tx_0 + wd_1)\frac{d\sigma_{rx_0}}{dx_0}$$

From eq 14,

$$\frac{d\epsilon}{dx_0} = \frac{1}{E}\frac{d\sigma_{rx_0}}{dx_0}$$

Then

$$E_t = \frac{E}{A}(4_{tx_0} + wd_1) = E\frac{A_e}{A} \qquad (9)$$

Equation 9 expresses the tangent modulus E_t in terms of x_0. This derivation is for $y_0 = 0$, which means that eq 9 is valid as long as the web remains elastic.

The relationship between the moment of inertia I_e and the yield condition as defined by x_0 was obtained in Appendix 3 (eq 17). Since both eqs 9 and 17 are in terms of $x_0(y_0 = 0)$ it is possible to express I_e in terms of E_t. Solving eq 9 for x_0 and substituting it into eq 17, the following equations are obtained relating I_e to E_t after neglecting some small terms,

$$\left.\begin{aligned} E\frac{I_{ex}}{I_x} &= \frac{AE_t - {}^2/_3 A_w E}{A_F + (A_w/3)} \\ E\frac{I_{ey}}{I_y} &= E\left[\frac{AE_t}{A_F E} - \frac{A_w}{A_F}\right]^3 \end{aligned}\right\} \qquad (10)$$

It will be recognized that the second of eqs 10 may be

expressed as the quantity Ek^3 (see eq 5). The first of eqs 10 is approximately equal to Ek. Equations 10 can be used until either the web starts to yield or the flanges have completely yielded. For the latter case the limiting E_t is obtained from eq 9 by setting $x_3 = 0$

Therefore it is seen that if E_t is determined from a "cross-section" stress-strain curve, eq 1 may be solved with the aid of eqs 10.

The various solutions derived in Sections 5 and 6 are compared in Fig. 6 considering flexure about the strong axis. (The various formulas for flexure about the weak axis are identical.) Equations 7 and 8 and eq 1 using expression 10 are compared. The "exact" solution is used in the later portion of this paper; it involves only a slight amount of extra work beyond the approximation of eq 7. In some applications, direct use of the tangent modulus (eq 8) may be sufficiently precise.

This completes the presentation of theoretical methods for computing the influence of residual stress on column strength. A description of test methods used to obtain a correlation with theory follows in the next chapter.

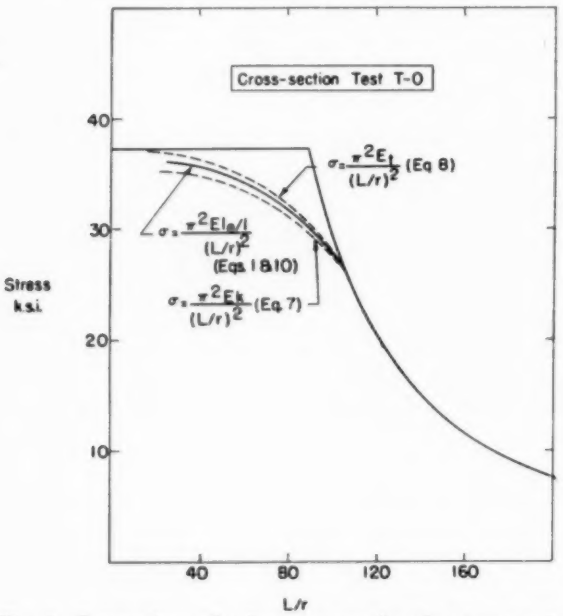


Fig. 6 Comparison of column curves for the strong axis —"exact" and approximate solutions

IV. DESCRIPTION OF TESTS

1. Test Program

The tests performed in this investigation are shown

Table 1—Test Program

Shape 8 WF 31

Test No.	*Type of test*	*Heat*	*Material condition*	*Specimen designation*	*Type of residual stress*	*No. of specimens*
T-0	Compression coupons	I	As-delivered	IB2.1	Cooling	4
T-0	Residual stress	I		IB2.2		1
T-0	Cross section	I		IB2.2		1
205*	Tension coupons	I		IB2.1		4
205A T-18	Column	I		IB2.4		1
205A T-15	Column	I		IB2.5		1
T-1	Tension coupons	I	As-delivered	IA2.2	Cooling	8
T-1	Residual stress	I		IA2.2		1
T-1	Cross section	I		IA2.2		1
205	Compression coupons	I		IA2.1		3
205	Tension coupons	I		IA2.1		4
205A T-11	Column	I		IA2.3		1
T-2	Compression coupons	I	As-delivered	IA1.1	Cooling	8
T-2	Residual stress	I		IA1.1		1
T-2	Cross section	I		IA1.1		1
205	Compression coupons	I		IA1.3		3
205	Tension coupons	I		IA1.3		4
205A T-25	Column	I		IA1.1		1
T-3	Compression coupons	I	Annealed	IB2a.2	Negligible	4
T-3	Residual stress	I		IB2a.2		1
T-3	Cross section	I		IB2a.2		1
T-4	Compression coupons	I	As-delivered	IB2.3	Cooling	4
T-4	Residual stress	I		IB2.3		1
T-4	Cross section	I		IB2.3		1
T-4	Column	I		IB2.3		1
205	Tension coupons	I		IB2.1		4
205A T-18	Column	I		IB2.4		1
205A T-15	Column	I		IB2.5		1
T-5	Compression coupons	II	Annealed	IIB3a.4	Negligible	4
T-5	Residual stress	II		IIB3a.4		1
T-5	Cross section	II		IIB3a.4		1
T-5a	Column	II		IIB3a.3		1
T-5b	Column	II		IIB3a.2		1
T-6	Variation of residual stress	II	As-delivered	IIB3.5	Cooling	8

* Designation "205" and "205A" indicates test performed as part of another program sponsored by WRC and ONR.

in Table 1. Note that the same test number applies to one series of tests consisting generally of coupon tests, residual stress measurements cross-section test and column tests. Some coupon and column tests (shown by test number "205" and "205A") were part of another program.* The specimen designation identifies the material. For example in the designation IB2.1, "I" is the heat, "B" is the rolling or ingot, "2" is the position (middle third) in the rolling and "1" is a specimen cut out of this piece.

The tests covered as-delivered and annealed material, two heats, two rollings in one heat and several locations in two rollings.

Only one shape, the 8 WF 31, was used in all tests. The as-delivered material used in the column tests, cross-section tests, residual strain measurements and coupon tests came from one ingot rolled in two parts (designated as rollings A and B). The member used for the investigation of the variation of residual stresses along its length came from a different heat. The two annealed columns and one annealed cross-section specimen were heat treated at the same time. A second cross-section specimen was annealed separately.

In summary, the following tests were performed as part of this program and will be described in detail later.

(*a*) Tension and compression tests of small coupon cut from positions next to the cross-section specimens.

(*b*) Six sets of residual strain measurements performed on pieces next to the cross-section specimens.

(*c*) Six "cross-section tests" of which two were annealed.

(*d*) Three axial column tests where bending was allowed in the weak direction. Two of these columns were annealed specimens. The results of four additional axially loaded column tests, (three "strong-axis," one "weak-axis") are also included.

(*e*) Study of the variation of residual stresses along a 9-ft member and the change in residual stress distribution within the member as it was shortened by successively cutting pieces from each end.

2. *Coupon Tests*

The dimensions of the tension coupons were selected according to ASTM Standards: full thickness of the material (flanges or web) and $1^1/_2$ in. width over an 8-in. gage length.

The dimensions of the compression coupons followed the recommendations of Research Committee A of the Column Research Council:† full thickness of the material, a coupon length smaller than $4^1/_2$ times the thickness and greater than twice the width plus gage length. In addition the gage length should be chosen greater than the width but smaller than twice the width

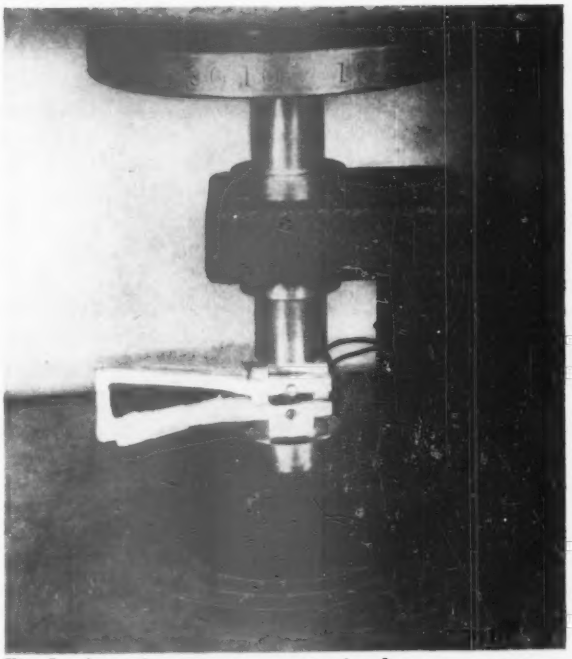


Fig. 7 Averaging compressometer in place on a compression coupon

of the coupon. The dimensions of the coupons cut from the web were approximately 1.35 x 0.29 x 0.40–0.50 in.* and 1.90 x 0.43 x 0.55–0.75 in. for those cut from the flanges. Some coupon test results included in Table 1 were already available when this program was started. Their dimensions were about the same as those given above except for the width which was 1.12 in.

All coupons were tested in a 60,000-lb hydraulic testing machine. The strains were measured in most cases with mechanical strain gages; in a few cases they were measured with bonded electrical resistance strain gages (Baldwin SR-4).

An 8-in. Moore extensometer was used in tension tests, while a pair of Huggenberger gages of $^1/_2$-in. gage length were used in compression tests. Some of the compression coupons were tested into the strain-hardening range by an averaging compressometer replacing the Huggenberger gages after passing of the yield point. Figure 7 shows the compressometer in place on a coupon. On the opposite sides of the vertical cross-bar, SR-4 gages are mounted so that strains may be measured up to 15% with an approximate sensitivity of 0.0002 in./in.

The coupons were numbered according to their location in the cross section as shown in Table 2.

Some of the compression coupons were provided with bearing blocks and a spherical bearing on top (Fig. 8), others were tested in a subpress (Fig. 7). All coupons were carefully aligned before the test to about one-third of the estimated yield load. The alignment was

* "Welded Continuous Frames and Their Components," sponsored by the Welding Research Council and the Office of Naval Research.

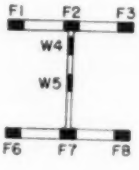
† "Notes on Compression Testing of Metals and the Column-Strength Curve," 1951.

* Length by thickness by width.

Table 2—8 WF 31 Material Properties

(All values in ksi)

Compression coupons						Tension coupons					
Material	*Specimen No.*	*E*	σ_p	σ_{u_y}	$\sigma_{y(c)}$	*Material*	*Specimen No.*	*E*	σ_p	σ_{u_y}	$\sigma_{y(c)}$
As-delivered											
IA1.1 (T-2)	F-1	29,250	17.0	..	36.8	IA1.1	No tension specimens				
	F-2	30,750	36.0	37.4	37.4						
	F-3	29,750	34.0	38.5	37.8						
	F-6	29,800	32.0	37.3	37.3						
	F-7	27,500	31.0	37.7	37.7						
	F-8	28,250	34.0	37.7	37.7						
	Avg-1*	29,220	30.6	37.7	37.4						
	W-4	29,000	36.0	43.1	43.1						
	W-5	25,500	17.0	42.3	42.3						
	Avg-1	27,250	26.5	42.7	42.7						
	Avg-2†	29,000	29.6	39.0	38.8						
IA1.3	F-1	32,800	..	40.0	39.5	IA1.3	F-2	30,300	..	39.8	37.9
	F-7	30,500	..	38.9	38.3		F-3	30,200	..	45.6	39.2
	F-8	30,500	..	40.0	39.7		F-6	30,200	..	43.0	40.3
	Avg-1	31,270	..	39.6	39.2		Avg-1	30,230	..	42.8	39.1
							W-5	30,200	..	44.8	43.3
							Avg-2	30,220	..	43.3	40.2
IA2.1	F-1	29,750	..	38.8	39.2	IA2.1	F-3	30,200	..	41.1	..
	F-7	30,400	..	39.7	39.6		F-6	29,400	..	40.9	..
	F-8	30,200	..	41.0	40.5		F-7	29,800	..	40.7	..
	Avg-1	30,120	..	39.8	39.8		Avg-1	29,800	..	40.9	..
							W-5	30,500	..	47.5	..
							Avg-2	30,010	..	42.5	..
IA2.2	No compression specimens					IA2.2 (T-1)	F-1	30,400	38.0	38.5	37.8
							F-2	29,800	27.0	41.0	40.5
							F-3	29,500	32.0	36.1	35.8
							F-6	30,750	38.0	40.1	38.5
							F-7	29,250	34.0	37.0	35.8
							F-8	31,000	24.0	36.3	36.2
							Avg-1	30,100	32.0	38.2	37.4
							W-4	28,000	21.0	..	34.0
							W-5	29,300	34.5	37.7	37.4
							Avg-1	28,650	27.7	37.7	35.7
							Avg-2	29,730	30.9	38.0	37.0
IB2.1 (T-0)	F-2	29,200	20.0	42.2	42.2	IB2.1	F-1	29,700	..	45.2	41.9
	F-3	28,800	29.0	40.0	40.0		F-2	30,200	..	41.4	38.1
	F-7	28,200	21.0	38.8	38.8		F-6	30,300	..	43.9	41.6
	F-8	28,700	36.0	39.0	39.0		Avg-1	30,090	..	43.5	40.5
	Avg-1*	28,700	27.2	40.0	40.0						
	W-5	29,200	17.0	42.5	42.5		W-5	30,200	..	46.6	44.2
	Avg-2†	28,780	24.7	40.6	40.6		Avg-2	30,100	..	44.2	41.4
IB2.3 (T-4)	F-1	29,750	38.5	40.3	40.1	IB2.3	No tension specimens				
	F-2	29,000	35.0	37.5	37.5						
	Avg-1	29,370	36.7	38.9	38.8						
	W-5	30,800	43.0	44.8	44.2						
	Avg-2	29,700	38.2	40.4	40.1						
Annealed											
IB2a.2 (T-3)	F-1	30,300	34.8	34.8	34.8	No annealed tension specimens					
	F-2	31,000	33.5	34.3	34.9						
	F-8	31,700	35.2	35.5	35.2						
	Avg-1	31,000	34.5	34.9	35.0						
	W-5	30,400	39.0	39.9	38.9						
	Avg-2	30,840	35.6	36.1	36.0						
IIB3a.4 (T-5)	F-1	30,400	34.2	34.2	34.2						
	F-2	28,700	32.1	32.3	32.1						
	F-8	30,200	33.0	34.3	34.3						
	Avg-1	29,800	33.1	33.6	33.5						
	W-5	29,200	34.0	35.3	35.3						
	Avg-2	29,650	33.3	34.0	33.9						



* Avg-1. Average value.
† Avg-2. Weighted average in proportion to flange and web areas.

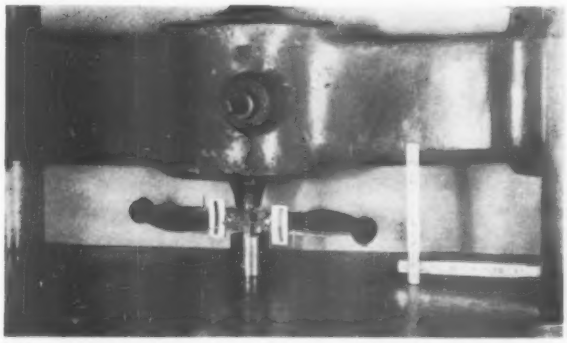


Fig. 8 Huggenburger extensometers in place on a compression coupon

considered satisfactory when the difference of strain readings on opposite sides of the specimens was from 2 to 3 times the sensitivity of the gage at one-third of the yield load. Where necessary, thin aluminum foils were used as shims.

The testing speed in the elastic range was approximately 1 micro inch /inch second for all coupons. In the plastic range the valve opening set in the elastic range was kept constant. Only coupons in series T-0 were tested beyond strain hardening. All other tests were discontinued at a strain of from two to four times the yield-point strain.

3. Residual Strain Measurements

The sectioning method was adopted for the measurement of residual strains because of its simplicity.[11] Strains were measured over a 10-in. gage length by a $^1/_{10,000}$ Whittemore strain gage on a series of previously laid out holes. Figure 9 shows a typical layout for the sectioning process. It was customary on this pilot program to take readings on both sides of the web and on both sides of each flange and to make the spacing of lines of gage holes equal to $^1/_2$ in. The 11-in. section to be cut out of the beam was at least 2 ft distant from the ends. Care was taken to select sections free from "yield lines" produced in the cold straightening operation at the mill. A standard 10-in. mild steel bar was attached to the specimen to observe changes in temperature during readings. The average error in these measurements corresponds to a stress of approximately ± 600 psi. Following an initial set of readings on drilled and reamed holes serving as gage points, a second set of readings was taken when the 11-in. section was sawed out of the beam as a unit. The final strains were obtained after the 11-in. section had been sawed into strips of $^1/_2$ in. width, each strip containing a pair of gage holes.

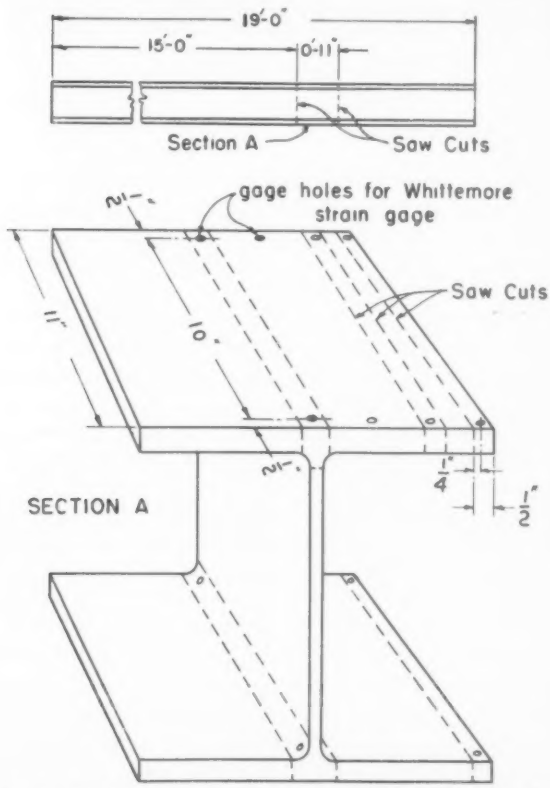


Fig. 9 Sectioning method for measuring residual strains

4. Cross-Section Tests

The length of the first of the "cross-section" speci-

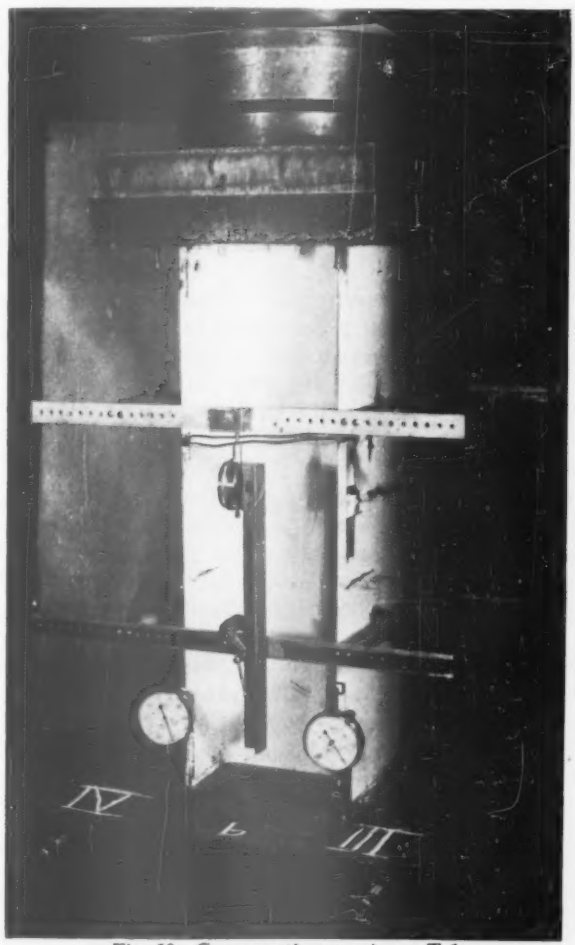


Fig. 10 Cross-section specimen T-1

mens was 20 in. The other five had a length between 24 and 26 in. Figure 20 shows that this length is sufficient to retain most of the original magnitude of residual stresses in the center part. Further comment on this point will be made later.

The specimens were tested in compression in an 800,000-lb screw-type testing machine as shown in Fig. 10. To obtain a uniform distribution of applied stress, bearing plates and a spherical bearing block were used between the specimen and the head of the testing machine. The ends of the specimens were milled flat.

The strains were measured by SR-4 gages of the A-11 type (1-in. gage length) except for one test where A-9 type gages (6-in. gage length) were applied. In addition, the average strain over a 10-in. gage length at the flange centers was measured on three specimens by a frame-dial gage combination illustrated in Fig. 10. The shortening of the specimens at the four flange corners was measured between top and bottom bearing plates with the aid of four dial gages and thin wire extensions; also they indicated any possible rotation of the head. The SR-4 gages and dial gages at the flange edges served for alignment and in addition supplied yielding and local buckling information.

The alignment of the specimens was made at loads not exceeding one-half of the expected residual-proportional limit (the load corresponding to yield stress minus the maximum compressive residual stress). The alignment was considered satisfactory if the maximum deviation of one corner gage from the average of the four corner gages was less than 5% at the maximum alignment load.

A qualitative picture of the yielding process was obtained by the flaking of the mill scale made clearly visible by whitewashing the specimens with hydrated lime (Fig. 11).

According to the assumption of linear strain increase over the total section, it is necessary to measure strains representing the average strain of the cross section at those locations expected to remain elastic for the greatest period of time. For the 8 WF 31 shape, these locations are in the web and at the flange centers which are usually found to contain tensile residual stresses. Theoretically, strains measured in the plastic portions should give the same strains as in the elastic portions; however, the mechanism by which yielding occurs in thin planes (yield lines) makes the measured strains depend on the gage length and the results are erratic.

The loads were applied in appropriate increments which were determined from the load vs. strain curve plotted during the test. After passing of the proportional limit, readings were taken after the maintained load and the strains had but negligible changes within a period of 15 min, the time required to take all readings. The criterion used was a change of less than $^1/_2$% in the load and less than 5% of the measured strains during the period. After the maximum load was passed a small increment of strain was applied by movement of the head of the testing machine and the readings were taken after both load and strains had stabilized.

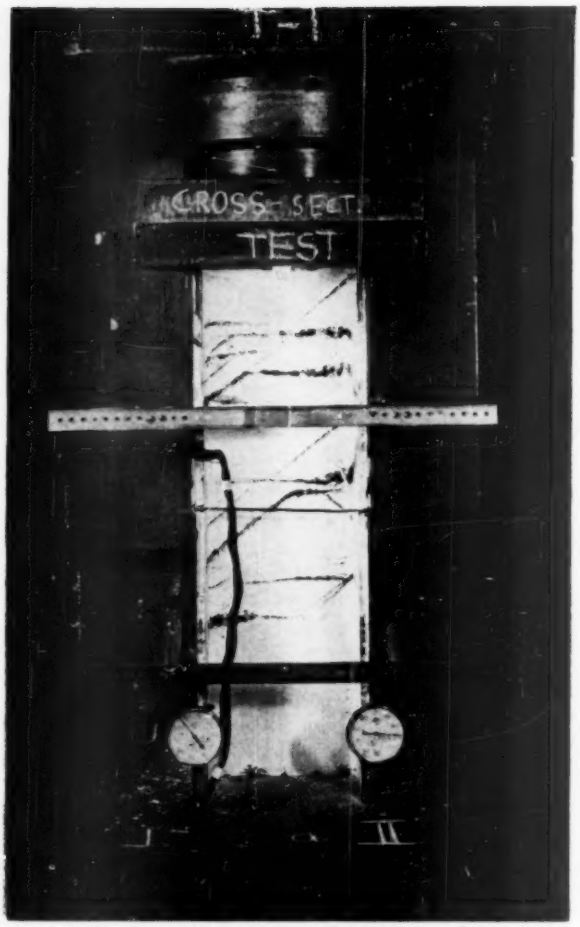


Fig. 11 Cross-section specimen T-1 after test (permanent set 0.0022 in./in.)

5. *Column Tests*

The columns were tested in the same 800,000-lb testing machine as the cross-section specimens. The axial load was applied through knife edges. A detailed description of the testing frame and the testing setup is contained in Reference 5.

Strains were measured by SR-4 gages of A-11 type (1-in. gage length) at locations close to both ends and at the center of the columns. The deflections were measured with dial gages located at the quarter points and at the center of the column. Deflections were also measured perpendicular to the plane of bending at the ends and at the center.

The alignment was checked by the SR-4 and the deflection gages. A very good alignment is essential to approximate as closely as possible the conditions assumed in theory; eccentricity and initial curvature may reduce appreciably the expected maximum loads. Accidental eccentricities were eliminated by relative movement of the column bases with respect to the base fixtures. Uneven bearing was remedied by movement of wedges. Both operations could be made while a small load was maintained on the column. The effect of initial curvature can be reduced somewhat by appli-

cation of a slight eccentricity; however, it can never be completely removed. For the tests reported herein all the effects described above were small compared with the reductions attributed to residual stress except for the column test 205A T-15 (Fig. 25) which had a relatively large amount of curvature. The alignment was made at loads not exceeding about one-third of the estimated maximum load. The deflection and strains at the center and near the ends were measured for the accuracy of the alignment. In most cases it was possible to obtain a deflection at the center of less than 0.1 in. at maximum load.

The load was applied in appropriate increments determined from a load-deflection graph plotted during the test. Again, near the maximum load a criterion had to be used to avoid appreciable changes of load, strains or deflections while readings were taken. Readings were taken if the change in load was less than $^1/_2\%$ and the change in deflection at the center of the column was less than 5% of the measured deflection. The tests were continued beyond the maximum load until the load had dropped to about two-thirds of the maximum value. In weak axis tests this drop occurred quite suddenly with no possibility of measuring intermediate values. Whitewashing of the as-delivered columns gave a qualitative picture of the development of yield lines. Although the cross sections were usually free from cold-bend yield lines, their presence could not be avoided in the columns. In all cases, the center part of the member was substantially free from cold-bend yield lines.

V. TEST RESULTS

For the tests performed as shown in Table 1, the following is a brief presentation of results for each type of test. These results are discussed and evaluated in Section VI.

1. Coupons

The results of coupon tests are listed in Table 2. Values of F, σ_p, σ_{uy} and σ_y are shown and corresponding tensile and compressive data are listed side by side. When a coupon showed the Bauschinger effect, the results were not used in determining average values for σ_p. The weighted averages are summarized in Table 3. In computing average properties, the values obtained from individual coupons at a particular cross section were weighted in proportion to the flange and web areas. The terms used in connection with coupon stress-strain curves are defined graphically in Fig. 12.

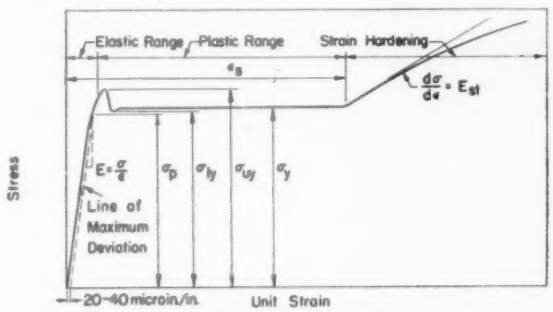


Fig. 12 Definition of terms

Table 3—Summary of Coupon Test Results

(Average values in ksi)

Material		E	σ_p	σ_{uy}	$\sigma_{y(c)}$
		Compression coupons (as-delivered)			
IA1	Flange	29,900 (9)*	30.6 (6)*	38.4 (8)*	38.0 (9)*
	Web	28,750 (2)	26.5 (2)	42.7 (2)	42.7 (2)
	Avg-2†	29,580 (11)	29.6 (8)	39.4 (10)	39.2 (11)
IA2	Flange	30,120 (3)	....	39.8 (3)	39.8 (3)
IB2	Flange	28,940 (6)	30.4 (6)	39.6 (6)	39.6 (6)
	Web	30,000 (2)	30.0 (2)	43.6 (2)	43.3 (2)
	Avg-2	29,200 (8)	30.3 (8)	40.6 (8)	40.5 (8)
Total	Avg-2	29,580 (22)	29.9 (16)	40.0 (21)	39.8 (22)
		Tension coupons (as-delivered)			
IA1	Flange	30,230 (3)	....	42.8 (3)	39.1 (3)
	Web	30,200 (1)	....	44.8 (1)	43.3 (1)
	Avg-2	30,210 (4)	....	43.3 (4)	40.1 (4)
IA2	Flange	30,010 (9)	32.0 (6)	39.1 (9)	37.4 (6)
	Web	29,270 (3)	27.7 (2)	42.6 (2)	35.7 (2)
	Avg-2	29,820 (12)	30.9 (8)	39.9 (11)	37.0 (8)
IB2	Flange	30,090 (3)	....	43.5 (3)	40.5 (3)
	Web	30,200 (1)	....	46.6 (1)	44.2 (1)
	Avg-2	30,120 (4)	....	44.2 (4)	41.4 (4)
Total	Avg-2	29,970 (20)	30.9 (8)	41.6 (19)	38.9 (16)
		Mill report tension test (as-delivered)			
	Web	....	....	43.3 (1)	....

* Number of specimens.
† Weighted average in proportion of flange and web areas.

The modulus of elasticity, E, was determined from a large-scale plot of the stress-strain curve and was taken as the slope of the average line through test points up to about the proportional limit. The maximum deviation of data points from this line was between 20 and 40 microinch/inch. The proportional limit, σ_p, was defined arbitrarily as the stress at which the average curve crossed the lower boundary of the scatter band (Fig. 12). The yield stress level σ_y was determined from the average stress in the plastic range.

Compression coupons tested into the strain-hardening range are shown in Fig. 13. Typical stress-strain curves for individual compression coupons are shown in Figs. 14 and 15.

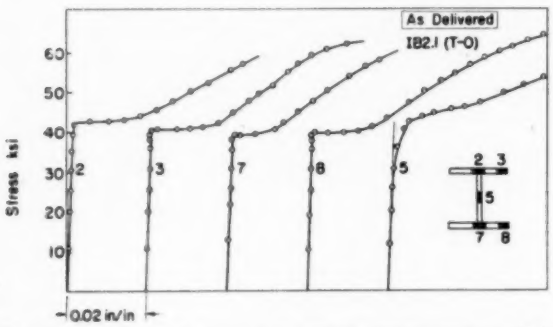


Fig. 13 Compression coupon stress-strain curves (T-0)

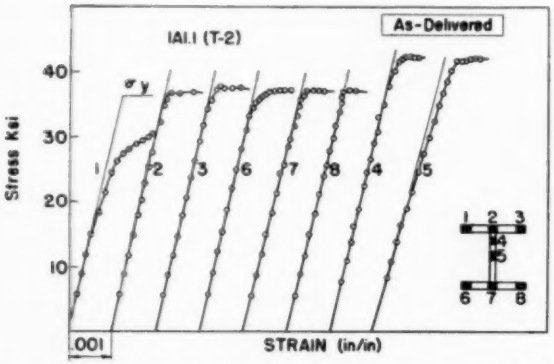


Fig. 14 Compression coupon stress-strain curves (T-2)

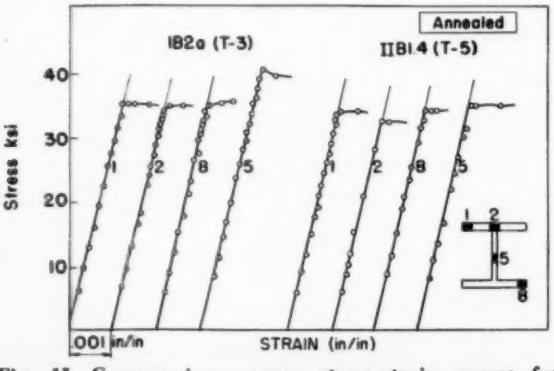
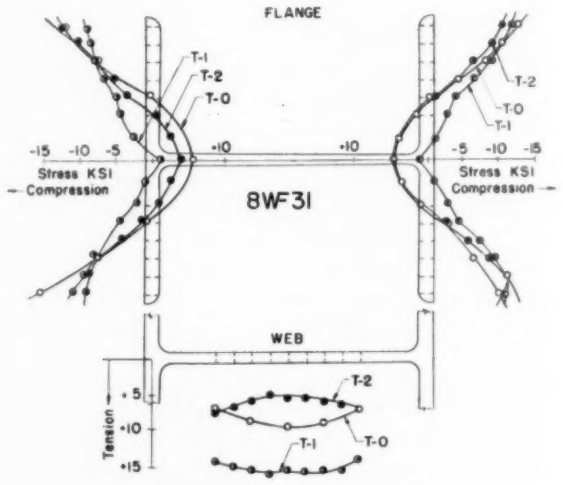


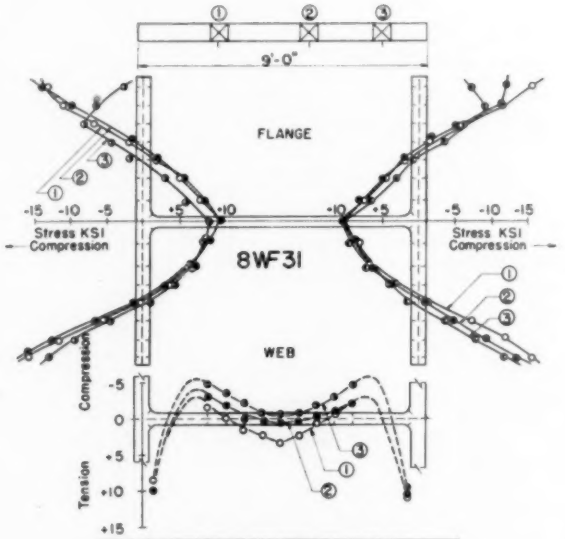
Fig. 15 Compression coupon stress-strain curves for annealed material

The average compressive stress-strain curve to be used for later comparison with cross section and column tests was determined from the above compression tests. The technique used is based on the assumption that plane sections remain plane after deformation and, thus, the axial strains are uniform across the section for each load increment. After plotting the individual stress-strain curves to a large scale, the stress values



AVERAGE RESIDUAL STRESSES (KSI)		
σ_{rc} (flange edge)	σ_{ro} (flange center)	σ_{rw} (web center)
-13.9	+5.6	+9.3
-11.5	+1.1	+15.5
-12.5	+4.2	+5.0

Fig. 16 Residual stress distributions (as-delivered)



AVERAGE RESIDUAL STRESSES (KSI)			
σ_{rc} (flange edge)	σ_{ro} (flange center)	σ_{rw} (web center)	σ_{rf} (web fillet)
-16.1	+10.1	+1.3	+9.7

Fig. 17 Residual stress measurements at three locations in a single beam (T-6)

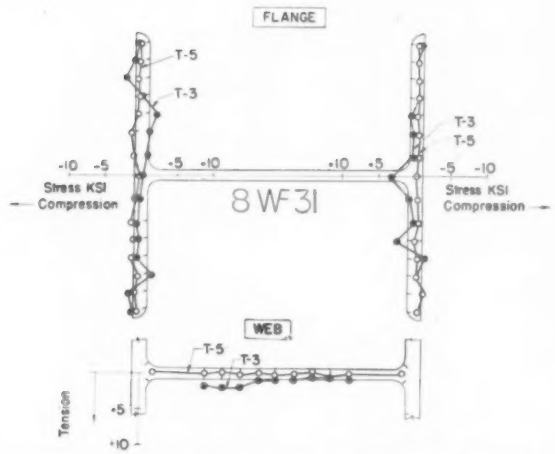


Fig. 18 Residual stresses in two annealed beams

are read from the various curves for predetermined strain values. Frequent strain intervals are selected in the region of the yield point. Individual stress readings of flange material are averaged for each of the selected strains and the same is done for the web material. Finally, for each of the strain values, a weighted average of stresses is determined in proportion to the relative flange and web areas. The average stress-strain curve is then plotted directly from this data.

2. *Residual Stress*

The residual stresses were computed from the measured strains using an elastic modulus of 30×10^6 psi. The distribution of these stresses in three as-delivered specimens is shown in Fig. 16. The results from T-4 are not shown but were quite similar to those obtained in T-0. These particular distributions represent two different rollings. In Fig. 17 are shown the results of residual stress measurements at three different locations in a single piece of material. In both Figs. 16 and 17 the distributions are shown separately for the flanges and the web. Except for a few measurements on T-6 (Fig. 17) the web is in residual tension (a maximum value of +16,000 psi was measured); the flanges are in compression at the edges (maximum value = −17,500 psi) and change to tension at the flange centers (maximum value = +11,000 psi).

The magnitude and distribution of residual stresses in two annealed specimens are shown in Fig. 18 and indicate that practically all the residuals were eliminated.

The results of the study on the variation of residual stresses along a member are shown in Fig. 19. A member 9-ft long received a layout of holes as shown in the upper sketches. At three locations a complete sectioning was made (76 pairs of holes) and the resulting stresses are shown in Fig. 17. At the other locations a partial sectioning was made involving 32 pairs of holes. The change of the residual stresses along the beam at the web center, the flange center and at the flange edges is shown in the lower portion of Fig. 19. The region containing cold-bend yield lines is to be noted.

Other measurements on the beam also served to study the changes of residual stress at a section for different lengths of cross section. As the sectioning process was performed at various stations along the member shown in Fig. 20 the member finally consisted only of the piece shown as *e-n* with a length of 31 in. At this stage, no change in readings had been observed over the gage

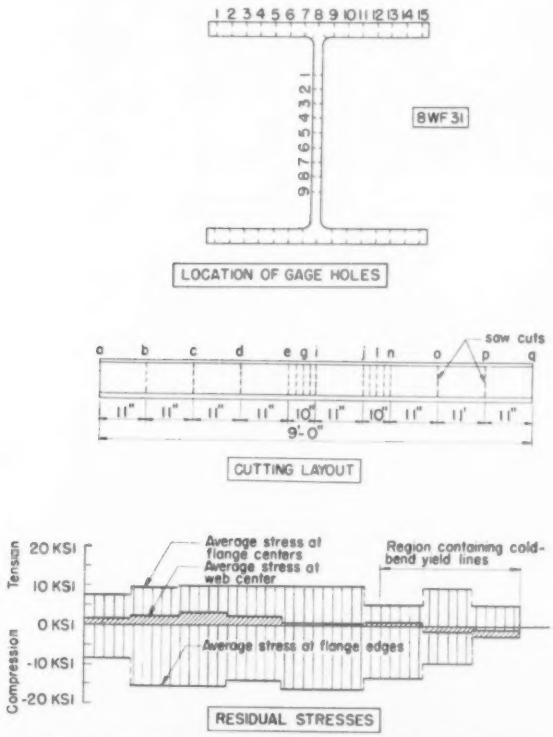

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
9 8 7 6 5 4 3 2 1
8WF31
LOCATION OF GAGE HOLES
a b c d e g i j l n o p q
saw cuts
11" 11" 11" 11" 10" 11" 10" 11" 11" 11"
9'-0"
CUTTING LAYOUT
Tension
Compression
20 KSI
10 KSI
0 KSI
-10 KSI
-20 KSI
Average stress at flange centers
Average stress at web center
Region containing cold-bend yield lines
Average stress at flange edges
RESIDUAL STRESSES

Fig. 19 Variation of residual stresses along a beam

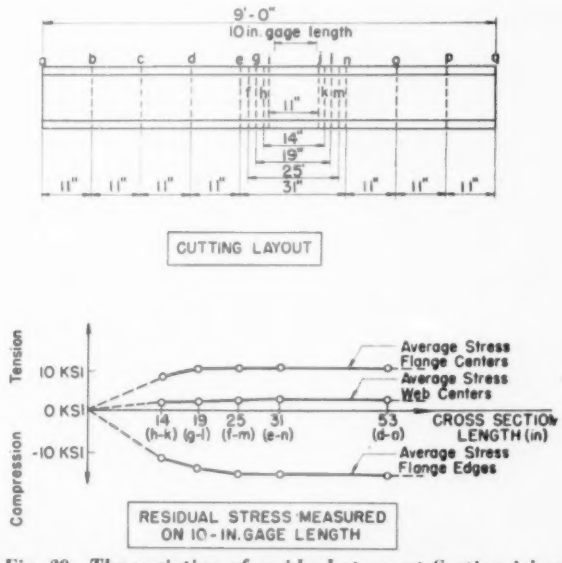


Fig. 20 The variation of residual stress at Section i-j as a function of cross-section length

Table 4—Cross-Section Test Results and Comparison with Compression Coupons

Material	*Condition*	*Test*	E	σ_p	$\sigma_y - \sigma_{rc}$	*First yield line*	σ_y
			Cross-section tests*				
IB2	As-delivered	T-O	29,400	25.6	23.41	29.65	37.31
IA2	As-delivered	T-1	30,100	28.0	24.70	28.26	36.20
IA1	As-delivered	T-2	29,600	25.2	25.27	24.89	37.77
IB2	As-delivered	T-4	29,340	27.0	22.82	29.16	36.72
Avg		...	29,610	26.4	...	...	37.00
IB2a	Annealed	T-3	29,760	26.0	...	...	33.35
IIB3a	Annealed	T-5	29,600	31.0	...	...	31.40
			Compression coupons*				
Material	*Condition*	*Test*	E	σ_p	$\sigma_{(yc)}$	$\sigma_y/\sigma_{(yc)}$	
IB2	As-delivered	T-0	29,200	30.3	40.5	0.922	
IA2	As-delivered	T-1	30,120	...	39.8	0.909	
IA1	As-delivered	T-2	29,580	29.6	39.2	0.963	
IB2	As-delivered	T-4	29,200	30.3	40.5	0.907	
Avg	.....	...	29,580	29.9	39.8	0.925	
IB2a	Annealed	T-3	30,840	35.6	36.0	0.927	
IIB3a	Annealed	T-5	29,650	33.3	33.9	0.926	

* All values in ksi.

length *i-j*. The remaining member (*e-n*) was then further reduced in length (25, 19, 14 and 11 in.) and finally cut into strips. The residual stress at this location is plotted vs. the length of "cross section" in Fig. 20 for the same locations as before; that is, at the web center, flange centers and flange edges. This figure shows that the residual stress distribution in the gage length *i-j* did not change appreciably until the total length was reduced to 19 in. Since all of the cross-section specimens were longer than 19 in., they had sufficient length to preserve almost completely the original residual stress pattern in their center portions. Of course this was important if the cross-section test was to reflect correctly the influence of residual stresses.

3. *Cross-Section Specimens*

The results of measurements of E, σ_p, and σ_y determined from the cross-section tests are summarized in Table 4 and compared with corresponding weighted compression coupon results.

The average stress-strain curves for typical cross-section specimens are presented in Figs. 21 to 23.* (Figure 23 is for the annealed material.) The average curve determined from compression coupons is also shown on each figure. In most cases strains were measured at several locations and these results are also presented in Figs. 21 to 23. Theoretically these latter curves should be identical according to the assumption of uniform strain.

The stress vs. tangent modulus curves needed to compute the column curves are shown in Fig. 24. (They also show the difference between measurements of the same specimen at different locations.) Column curves based on the stress-strain curves of coupons and of

* In Figs. 21 and 22 the strain ϵ_5 is the theoretical strain at which the cross section should reach the yield stress level. See Fig. 41.

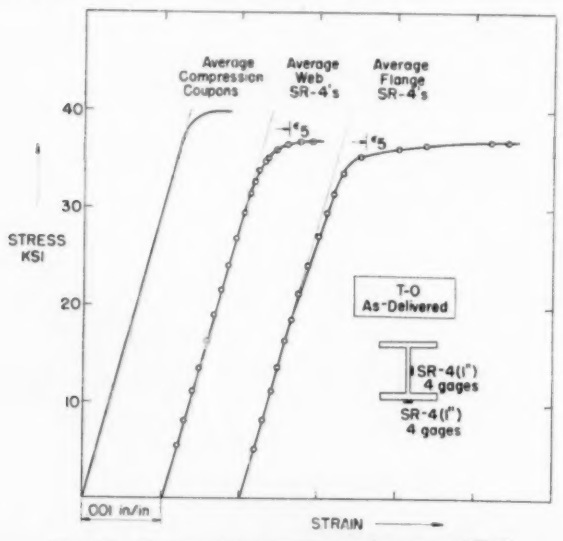


Fig. 21 Cross-section stress-strain curves (T-0)

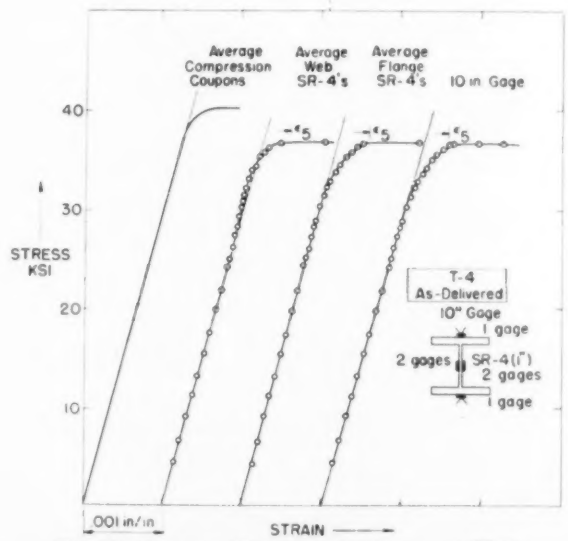


Fig. 22 Cross-section stress-strain curves (T-4)

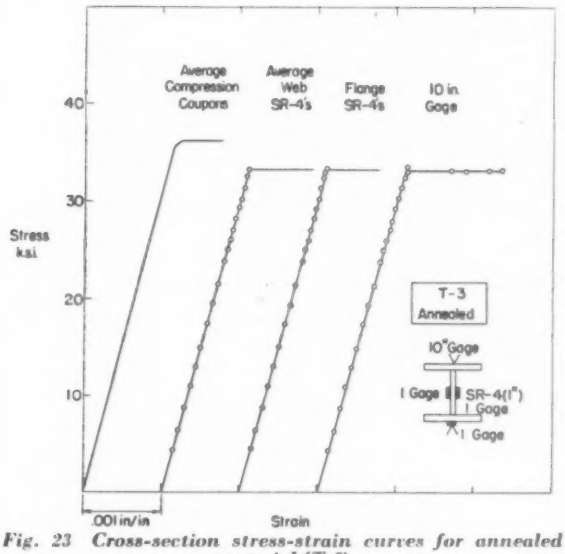


Fig. 23 Cross-section stress-strain curves for annealed material (T-3)

cross sections and using the relationships in Chapter III, Section 6 of the report are shown in Figs. 25, 26, 27 and 28. (Column test results are shown in each case for comparison.) Figure 25 (T-0) compared results from web SR-4 gages and flange SR-4 gages. Figure 26 (T-4) also contains column curves from residual stress measurements as will be described below. Column curves for the two sets of annealed material are shown in Fig. 27.

In order to compare all the cross-section test results, Fig. 28 has been prepared. It presents the data on a nondimensional basis to eliminate the effect of differences in the material properties. The values of E and σ_y used in the figure were taken from the corresponding stress-strain relations. σ_y was the maximum average stress carried by the cross sections; it was also applied to the column test results. For the coupon curves, σ_y was taken as the weighted average of the yield stress level.

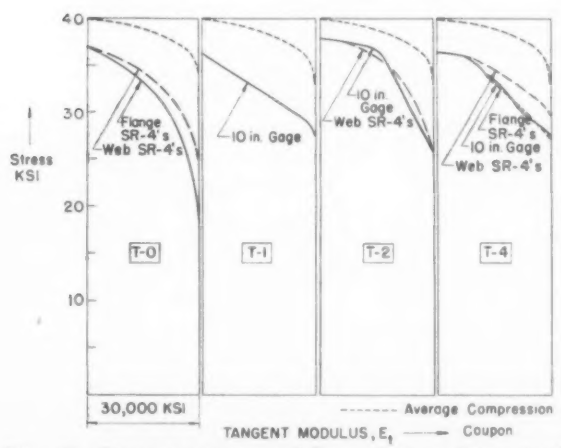


Fig. 24 Stress-tangent modulus relation determined from cross-section tests

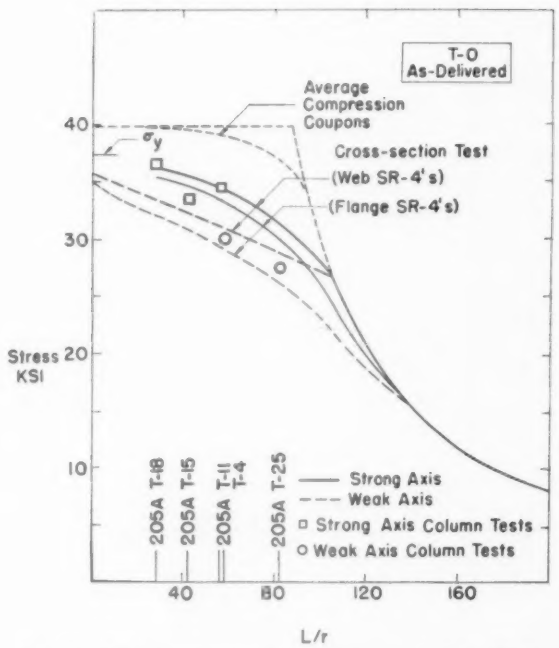


Fig. 25 Column curves and column test results (T-0)

By the method of Chapter III, Section 3, of this report, column curves from residual stress measurements are plotted in Fig. 26 in addition to the curves based on cross-section tests. Straight lines were used to approximate the actual residual stress pattern. The magnitude of σ_y was taken as 93% of the value determined from coupon tests. Figure 29 corresponds with Fig. 28 and presents all the results on a nondimensional basis.

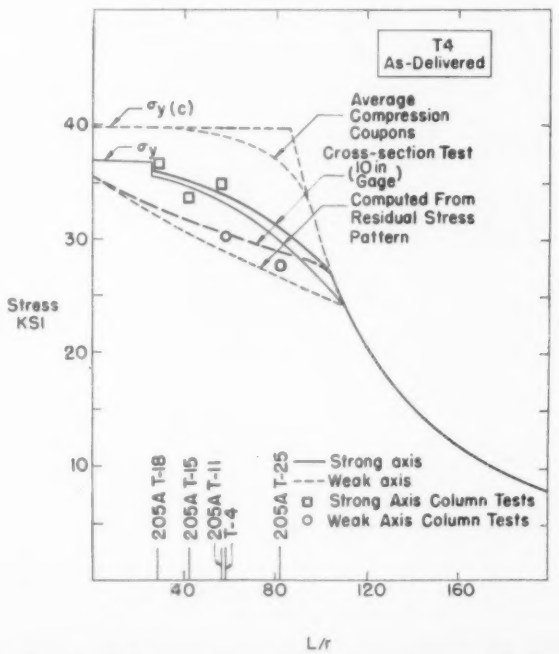


Fig. 26 Column curves and column test results (T-4)

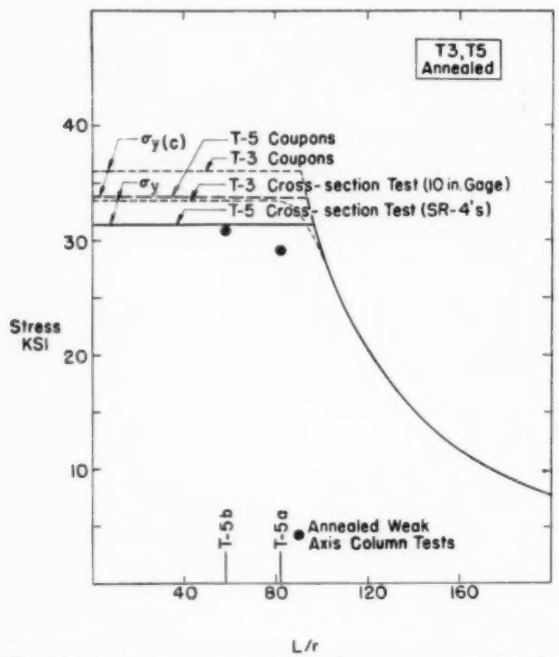


Fig. 27 Column curves and column test results for annealed material

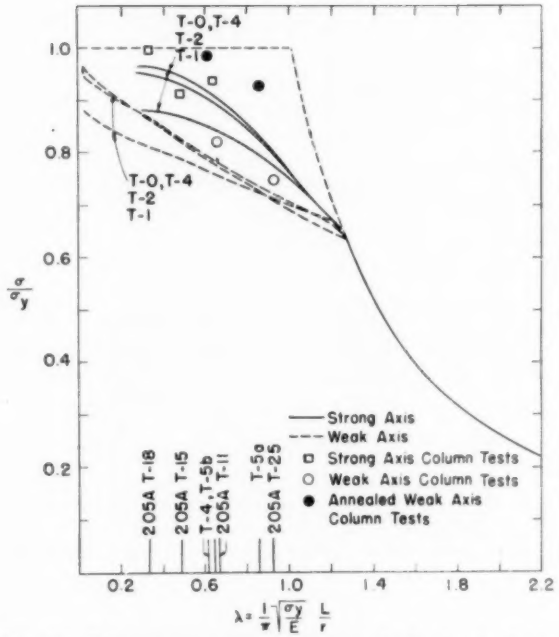


Fig. 29 Column curves computed on the basis of a linear distribution of residual stresses

4. Columns

The maximum average stresses carried by the columns have been plotted on Figs. 25 and 26 for as-delivered material and in Fig. 27 for the annealed material. Figures 28 and 29 compare all of the column tests to the various theoretical curves on a nondimensional basis.

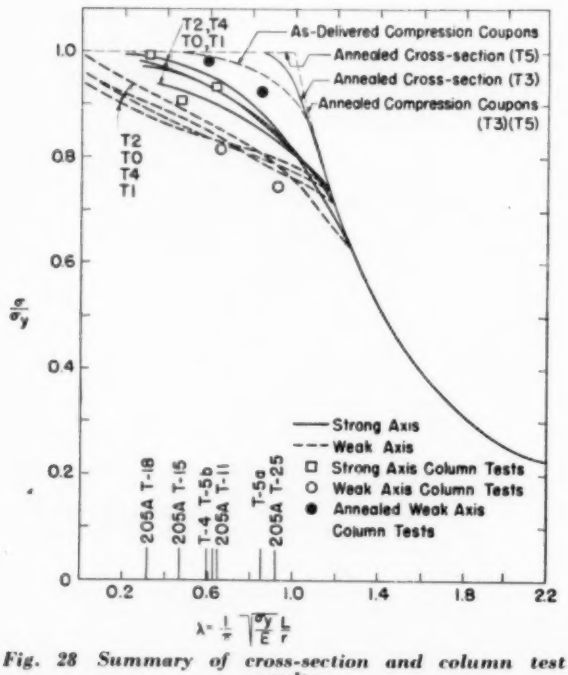


Fig. 28 Summary of cross-section and column test results

Load vs. center deflection is plotted for a number of tests in Fig. 30. Theoretically, a concentrically loaded, ideal column should not deflect until the tangent-modulus load is reached. In tests, slight deflections are observed from the start. Table 5 gives the approximate values of eccentricity and center deflection if the observed deflections were attributed to (*a*) initial

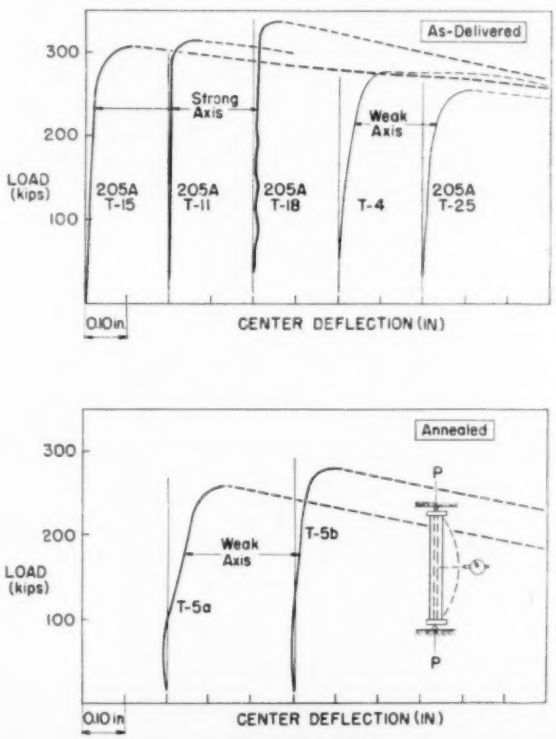


Fig. 30 Column deflection curves

Table 5—Equivalent Eccentricities and Initial Curvatures

Test	*P, kips*	*L, in.*	δ/L	*e, in.*	ec/r^2	*a, in.*	
205A T-15	200	146	0.018	0.097	0.032	0.119	Strong axis
205A T-11	200	194	0.002	0.005	0.002	0.007	
205A T-25	200	164	0.025	0.020	0.020	0.026	Weak axis
T-4	200	116	0.016	0.038	0.038	0.048	
T-5a	200	164	0.045	0.037	0.037	0.046	
T-5b	200	116	0.012	0.027	0.027	0.036	

curvature or (*b*) initial eccentricity only. The initial curvature was assumed to be a sine curve with amplitude *a*. The table also shows the corresponding values of ec/r^2. A comparison with a study recently published[10] shows that except for 205A T-15 the reductions due to eccentricity were small when compared with the theoretical reductions due to residual stresses. All columns were within AISC rolling tolerances of $^1/_8$ in. per 10-ft length of member.[2]

VI. DISCUSSION

1. *Compressive Strength*

The compressive strength of steel as measured by the yield stress level is somewhat lower than the value that is obtained in the ASTM-type acceptance test; likewise, although compression and tension coupons give results that are almost identical (on the average), the compressive strength of full cross sections is less than that obtained by averaging the results of small coupons tested in compression.

The comparison between the results of tension and compression coupons shown in Table 3, supports the usual assumption of identical behavior of steel in tension and compression. The elimination of compression testing of coupons (in the case of rolled structural steel shapes) is thus considered as warranted, particularly in view of larger variation in properties due to other causes.

There was considerable variation in coupon properties (both compression and tension) particularly between web and flange material (Table 2). On the average, the yield stress level was 10% higher for web material than for flange material. Since web material is normally used for the acceptance test, and since this variation between web and flange material has been observed in numerous other tests, it can be expected that the average compressive strength of a full cross section will be lower than that obtained in an acceptance test by an amount varying from 0 to 10%. The difference in strength has been attributed to the more rapid cooling rate of the web material as compared to the thicker flange material.[9]

Difference in strength of as much as 10% was also observed between different locations in the same flange (Table 2). However, when weighted averages are compared for different locations in the same ingot, the agreement is much better (about 2% in the compression tests). Some coupons exhibited a Bauschinger effect (coupon No. 1 in Fig. 16). "Cold-bend" yield lines produced during straightening of beams in the mill were positively identified on the coupon mentioned. It is the previous tensile strain that accounts for this behavior.

The difference in strength between full cross sections and the weighted averages obtained from coupons is evident in Table 4. The maximum stress carried by the cross sections varies from 90 to 96% of the yield stress level of the compression coupons. This reduction also appeared in the case of annealed tests and has also been observed in other tests. The difference in strength may possibly be due to size of specimen, shape of specimen or both. At any rate, because the entire member is used, test of a full cross section is a more rational indication of strength than is the average obtained from a large member of coupon tests. The cross section is also less expensive for laboratory use than are coupons, the cost ratio being about 2 to 3 for cross-section cost vs. cost of 8 compression coupons.

Incidentally, the agreement between modulus of elasticity, *E*, as obtained from compression coupons and from cross sections was excellent (Table 4). Four of the coupon sets exhibited *E* values that agreed within $^1/_2$% with the corresponding cross sections, and the maximum difference in *E* was 3%. The average value was 29.6×10^6 psi.

Figure 31 summarizes diagrammatically the influence of several factors on the strength of steel in comparison with the value obtained in an acceptance test. The strength obtained in this test is usually, though not always, based on the upper yield point. (In Table 3

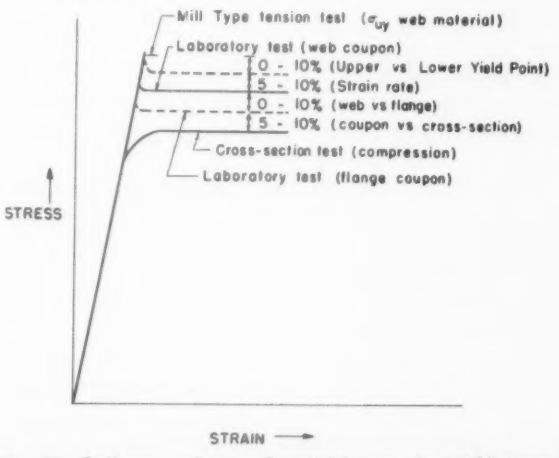

Mill Type tension test (σ_{uy} web material)
Laboratory test (web coupon)
0 - 10% (Upper vs Lower Yield Point)
5 - 10% (Strain rate)
0 - 10% (web vs flange)
5 - 10% (coupon vs cross-section)
Cross-section test (compression)
Laboratory test (flange coupon)
STRESS
STRAIN

Fig. 31 Influence of several variables on the yield stress level, σ_y

the upper yield point in tension was 5% higher than the lower yield stress level.) The difference in rate of strain could account for a further reduction of 10%; difference in strength between web and flange accounts for from 0 to 10% reduction; finally, the full cross section is from 5 to 10% weaker than that indicated by coupon tests. Thus a full cross section tested in the laboratory in compression may be expected to show a lower yield stress level which is 10 to 30% lower than the tensile yield point determined in the routine ASTM acceptance test. Future work is aimed at specifying more precisely the strength of steel in compression.

The effect of annealing is, of course, to reduce the compressive strength somewhat (Table 2). Even in the annealed state the web was still stronger than the flange.

2. *Magnitude and Distribution of Residual Stress*

Figures 16 and 17 indicate that compressive residual stresses at the flange tips amounted to as much as − 17,500 psi and in the web reached values of − 5000 psi. Tensile residual stresses were as much as +16,000 psi in the web and +11,000 psi at the flange centers. These are average stresses calculated from measurements on both sides of the webs and outstanding flanges. The difference between readings on such pairs of holes was in most cases of the same order of magnitude as the error of the measurements. However, a trend of slightly higher stresses seems to be indicated on the outside flange surfaces as compared with the inside surfaces.

There were several typical patterns (distributions) of residual stress in flange and web (Figs. 16, 17). The distribution of flange stresses was in some cases linear and in others parabolic, hyperbolic or "S-shaped." The distribution of stresses in flanges and web are interrelated since the condition of equilibrium requires that the resultant web force balance the resultant in the two flanges. For example, in Fig. 16, T-1 shows a relatively high resultant compressive force in the flanges; as a consequence, the tensile force in the web is relatively high. Although not so marked, a similar correlation is seen between T-0 and T-2. In Fig. 17, the flange is so nearly in equilibrium that there is little resultant force in the web. The influence of the different distributions of residuals will be examined in Section 4.

The annealed material (Fig. 18) had residual stresses of such small magnitude that the measuring method employed was not sufficiently sensitive to determine them precisely. Thus Fig. 18 cannot be considered to represent an actual stress distribution since the recorded values are of the same magnitude as the possible errors. However, the purpose of these measurements was only to verify that annealing had eliminated the residuals.

3. *Variation of Residual Stresses*

The magnitude of the stresses at flange tips show relatively small variation. Stresses at flange centers show larger variation (Fig. 16) and those in the web show the greatest of all.

Considering first the material from one ingot (Fig. 16) there is some variation in distribution of stress in the flanges of different rollings and a much bigger variation in the webs. This latter variation has only a small influence because column strength is primarily determined by the residual stresses in the flanges.

The material from the second heat had much higher tensile stresses at the flange centers (Fig. 17). Except for magnitude of compressive stress at flange edges, the variations between two different heats were rather large (compare Figs. 16 and 17). Measurements at different locations on the same beam indicate good uniformity (Figs. 17, 19) except for one end which contained yield lines from cold bending. Considering the variation along the member, the full magnitude of residual stress is reached after a short distance of approximately 1 ft from the ends (Fig. 19). This is in agreement with the results presented in Fig. 20 where a minimum length of about 3 times the section depth or flange width is seen to be sufficient to preserve the residual stress pattern at the center of the specimen.

In summary, the assumption made earlier that the

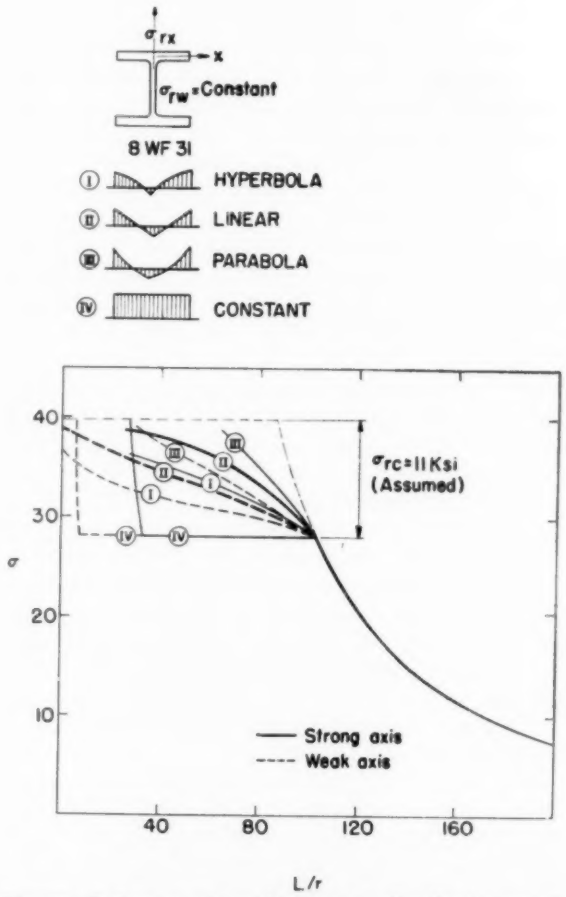


Fig. 32 Influence of residual stress distribution upon column strength

distribution of cooling residual stresses is uniform along a column seems to be reasonable. It is further borne out by column tests, where yielding is usually observed to occur rather uniformly along the member.

4. *Influence of Residual Stress Distribution Upon Column Strength*

Four possible distributions of residual stress are considered as shown in the top diagram of Fig. 32. The web stresses were assumed to be constant and of a value to satisfy equilibrium. The analysis was carried out until the flanges had yielded completely or until the web had reached the yield point as was the case for the parabolic distribution (Curve III). Column curves were than drawn for each case and for flexure about either the strong or the weak axis as indicated. As between patterns I, II and III, the greatest reduction was caused by the hyperbolic distribution (Curve I). The result obtained from T-1, which had a residual stress distribution approaching Pattern I is in confirmation of the prediction of Fig. 32. The cross-section column curve plotted in Fig. 28 is the lowest for this test.

A fair average of these cases is supplied by the linear pattern of residual stress.

In general a large area of compressive residual stresses in the flanges results in a lower column curve. A limiting case would be compressive residual stresses throughout the flanges and tension in the web. The column curve would become horizontal at a stress $\sigma_y - \sigma_{rc}$ as shown by Curve IV, Fig. 32. Recent model tests* confirmed this behavior.

5. *Influence of Residual Stress—Correlation Between Theory and Tests*

Of first importance in considering the influence of residual stress is the reduction in strength of columns below the strength predicted on the basis of average compression coupon curves. Figure 25 serves as illustration; by no means could "coupon" curves serve as a rational basis for predicting as-delivered column strength. The reduction amounts to as much as 35%.

Secondly, the influence of residual stress is different depending on the flexure axis. As predicted by theory the influence of residual stress is more pronounced for columns bent about the weak axis.

The two methods for predicting theoretically the influence of residual stresses were treated in Chapter III of this paper and have the same fundamental basis. In both cases a relationship between average applied stress, σ, and elastic moment of inertia, I_e, is desired. To find this relation certain material properties are required and these must be furnished by tests. These methods will now be discussed and correlated with column tests.

(*a*) *Method Based on Residual Stress Distribution.* The method requires the measurement of residual stresses by sectioning a piece of the material or by some other process. Numerous coupons must be tested and a factor (90–95%) applied to the yield stress level to arrive at an equivalent basic compressive strength. The residual stress pattern must then be approximated by an appropriate analytical expression and the resulting column curve computed according to Section 3 of Chapter III of the report.

Errors can be made in the measurement of residual stresses (±600 psi) and in the measurement of E and σ_y in the coupons. Care must be taken that residuals are measured in a piece free of cold-bending yield lines. It is impractical to go to too much refinement in approximating analytically the residual stress distribution. Figure 32 shows further that a reasonable approximation to the pattern produces a satisfactory column curve.

In Fig. 26 test results are compared with typical curves computed from residual stress patterns. The agreement is satisfactory. The same comparison for all tests, the results being plotted nondimensionally, is shown in Fig. 29. In all these calculations a factor of 93% was applied to $\sigma_{y(c)}$ obtained from coupons to give the basic compressive strength.

(*b*) *Method Based on Cross-Section Test.* Correlation between actual column tests and the results of the analysis of "cross sections" containing residual stresses is shown in Figs. 25, 26, 27 and 28. The agreement between theory and test is as good as is the "residual stress" method, and the scatter in results obtained from different cross sections is not unreasonable. The results of both the "cross section" and the "residual stress" analyses are shown in Fig. 26 together with test results. In this respect there is little basis for choosing one over the other.

The "cross-section" method for determining the influence of residual stress on column strength requires a length of material sufficiently long to retain most of the residual stress intensity at the center. This may be accomplished if the length is of the order of three times the depth of member or width of flange. Testing of the full cross section provides, directly, values of E, σ_y and σ_{rc}. By determining the values of E_t at various stress levels and using the expressions in Section 6 of Chapter III, column curves are obtained.

There are advantages of time and money in the cross-section scheme as compared with the residual stress method, presuming that the residual stress distribution is symmetrical. Of course, errors may be made in determining E_t and σ_y. Care must be taken in the conduct of the test, particularly in the alignment. Theoretically, strain measured at different locations should be identical. However, variation is often observed and this leads to differences in the stress vs. tangent-modulus relationship (Fig. 24). Considering the worst discrepancy between different sets of

* Cherry, S., Chow, P. Y., and Austin, W. J., "Experimental Studies of Model Columns," Structural Research Series No. 34, University of Illinois (July 1952).

gages (as observed in T-0) two separate column curves have been drawn in Fig. 25. In the one case SR-4's were mounted on the web and in the other on the flanges. Even for this extreme case, the difference is small compared with the reduction from the average coupon curve.

The cross-section method allows the determination of the column curve until the flanges have completely yielded (the limiting value of E_t is found in Chapter III). The corresponding stress is so close to the yield stress level that the curve may simply be extended to σ_y without serious error.

Fair agreement was observed between the predicted first yielding ($\sigma_p = \sigma_y - \sigma_{rc}$) and the load at which flaking of whitewash occurred. Thus the cross-section test permits a rough estimation of σ_{rc}, the compressive stress at the flange edges.

Incidentally, the residual stress magnitude and distribution in the flanges may be reconstructed from the measured stress-strain curve of a cross-section specimen. The procedure is as follows: the average strain in terms of the residual stress at a point was given by eq 14 (Appendix 3) as

$$\epsilon = (1/E)(\sigma_y - \sigma_{rx_0})$$

The tangent modulus was given by eq 9 as

$$E_t = \frac{E}{A}(4tx_0 + wd_1)$$

Since σ_b, E, E_t and ϵ are determined from the test, σ_{rx_0} may be determined from eq 16 for discreet values of ϵ and the corresponding x_0 may be obtained from eq 9. A comparison between computed values of residual stress with actual measurements is shown in Fig. 33: the agreement is quite good. The variation of the calculated stresses is due in part to the experimental error involved in obtaining the tangent modulus, E_t.

Column test 205A T-15 (Fig. 25) showed a reduction below the expected value; this was due to a relatively large initial curvature present in the member.

The results of annealed tests, shown in Fig. 27, exhibit the difference between coupon yield stress level and cross-section strength that was also seen in the as-delivered material. No column tests were made for T-3 material. T-5b almost carried the full yield load. The longer column, T-5a, showed some reduction which is probably due to both out of straightness and eccentricities, their influence on the deflection curve being seen in Fig. 30. The theoretical column curves based on cross-section tests shows clearly that residual stresses have largely been eliminated by annealing. This series of annealed tests gives conclusive evidence of the presence and influence of residual stresses.

The summary curve of Fig. 28 also contains the results of the study of annealed material. Comparison of the weak axis tests (solid circles are for annealed material, open circles as-delivered), show the reduction in strength due to residual stress which is in confirmation of the theory.

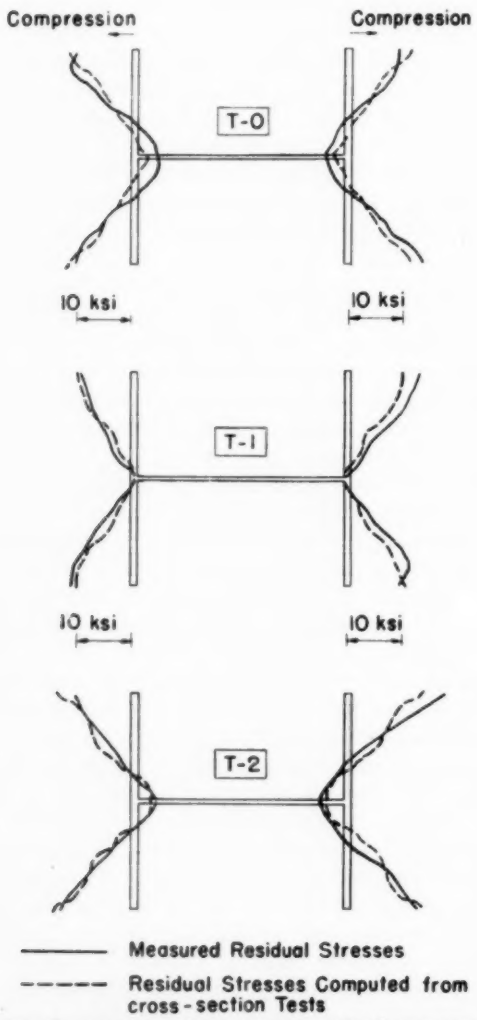


Fig. 33 Comparison of measured residual stresses with stresses computed from cross-section tests

6. *Basic Column Strength*

In Fig. 34 the average cross-section curve is plotted.

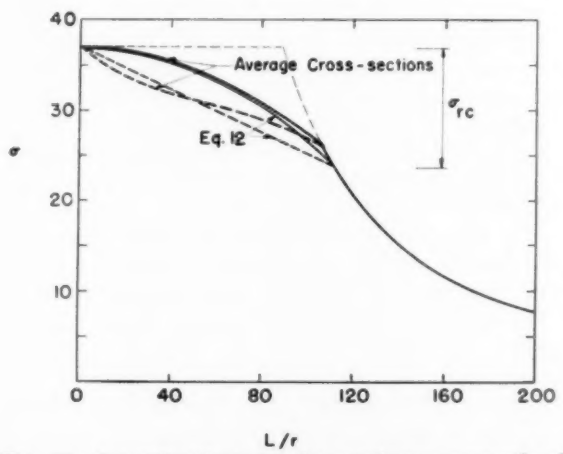


Fig. 34 Approximations to the maximum strength of wide-flange steel columns

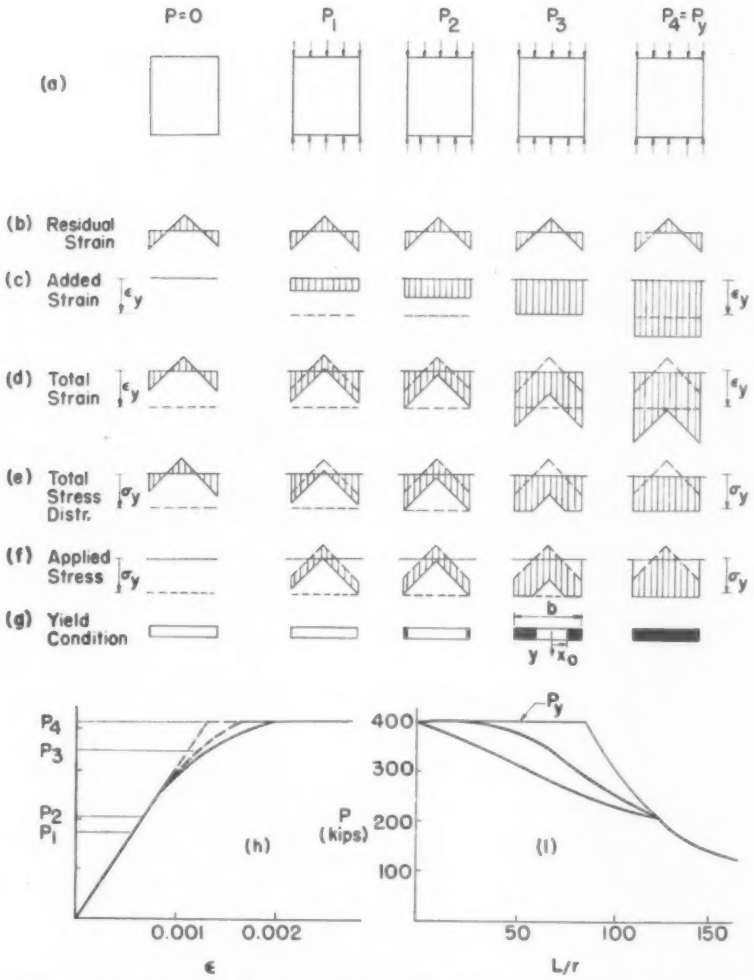


Fig. 35 The behavior of rectangular specimen containing residual stresses

It will be noted that the curve for buckling in the strong direction is approximately parabolic in shape, while the weak axis curve shows approximately linear behavior. The two curves could be expressed by the following simple relationships:

$$\sigma_{x-x} = \sigma_y - \frac{\sigma_{rc}}{\pi^2 E}(\sigma_y - \sigma_{rc})\left(\frac{L}{r}\right)^2$$

$$\sigma_{y-y} = \sigma_y - \frac{\sigma_{rc}}{\pi}\sqrt{\frac{(\sigma_y - \sigma_{rc})}{E}}\left(\frac{L}{r}\right) \qquad (11)$$

where σ_{rc} is the residual stress at the flange tips. Using the average material properties measured in the tests ($\sigma_y = -37{,}000$ psi, $E = 29.6 \times 10^6$ psi and $\sigma_{rc} = -14.000$ psi) eq 11 may be written as

$$\sigma_{x-x} = -37{,}000 + 1.10\,(L/r)^2$$
$$\sigma_{y-y} = -37{,}000 + 124.0\,(L/r) \qquad (12)$$

These curves are also shown in Fig. 34, together with the average cross-section curves.

VII. CONCLUSIONS

The following are some of the conclusions resulting from the Pilot Program on the influence of residual stress on the column strength of wide-flange structural shapes and are limited to those cases in which the residual stress distribution in such shapes is approximately symmetrical.

1. The presence of residual stresses results in a considerable lowering of column strength below values predicted on the basis of coupon tests, especially in the region of effective slenderness ratio of about 90.

2. Residual stresses in the flanges are of more pronounced influence on column strength than are residual stresses in the web. In most cases an assumed linear distribution of residual stress in the flanges results in a fair average column curve (Fig. 32).

3. There is a pronounced difference in behavior of as-delivered columns that is dependent upon the axis about which the column bends. This difference is due to the influence of residual stress. Columns of a given slenderness ratio in the weak direction, allowed to bend in that direction, will carry less load than columns of the same slenderness ratio in the strong direction, allowed to bend in that direction (Fig. 28) This results from the fact that the highest compressive residuals are found at the tips of the flanges.

4. The variation of residual stresses along a member free from cold-bend yield lines is small (Fig. 19). The variations of residual stresses within material from one ingot are relatively small (Figs. 16, 17), but larger variations may exist between material from different lots.

5. The magnitude and distribution of residual stresses present in a long beam is preserved at the center part of a piece cut out of the beam if the length is about three times the depth of the section.

6. The yield stress level of a full cross section tested in compression is as much as 10% lower than the value obtained from compression coupons (Fig. 31, Table 4). Since the same behavior is observed in annealed material, residual stress does not appear to be accountable. It is possibly due to an influence of size and shape of specimen.

7. Factors such as upper yield point, strain rate and web strength vs. flange strength when added to the reduction due to size or shape effect may result in a full cross section tested in the laboratory in compression showing a yield stress level markedly less than the tensile yield point determined in the routine ASTM

acceptance test (Fig. 31). Further research should establish the variation more precisely.

8. Modulus of elasticity, E, and effective compressive yield stress, σ_y, are obtained in satisfactory manner from the test of a full cross section (Table 4). Further, the column curve computed from the cross-section stress-strain relation by application of tangent modulus theory is in good agreement with the solution based on residual stress measurements (Fig. 26) and with test results (Fig. 28). This test is therefore an effective laboratory tool for obtaining basic compressive properties of steel sections and for predicting column strength.

9. Rather simple formulas are developed which approximate closely the theoretical and experimental column curves for failure loads of as-delivered wide-flange shapes (eqs 11 and 12). As more statistical data are collected on the properties of rolled steel shapes (E, σ_y, σ_{rc}) and in particular on the relationship between the results of the ASTM acceptance test and the basic yield stress of a full cross section, a specific formula may be put forward for the maximum strength of steel WF shapes. With such a formula as a basis, and taking into consideration such matters as crookedness, eccentricities, end restraints and the factor of safety, current design formulas can be critically examined.

VIII. ACKNOWLEDGMENT

This work has been carried out at Fritz Engineering Laboratory of which Prof. William J. Eney is Director.

The authors wish to express their appreciation to the sponsors of this research program; namely, the Column Research Council, the Pennsylvania Department of Highways and the Bureau of Public Roads. Acknowledgment is also expressed for the suggestions received from members of Research Committee A (Column Research Council), particularly those of its chairman, Bruce G. Johnston, who was very active in efforts to initiate studies of residual stress influence.

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Acknowledgment is also due to Kenneth R. Harpel, foreman, and the staff of machinists and technicians at the Fritz Engineering Laboratory.

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X. Appendixes

APPENDIX 1: NOMENCLATURE

A	= cross-sectional area
A_e	= area of the unyielded part of the cross section
Af	= area of both flanges of WF shape
$A_w = wd_1$	= approximated web area
b	= flange width
d	= depth of section
$d_1 = d - t$	= depth of WF section between center lines of flanges
E	= Young's modulus of elasticity
E_t	= tangent modulus
I	= moment of inertia
I_e	= moment of inertia of the unyielded (elastic) part of the cross section
L	= total length of a pin-ended column
L/r	= slenderness ratio
P	= load on a column
P_{cr}	= critical load on a column; in the case of axial load alone it is P_e for buckling in the elastic range
P_e	= Euler buckling load for a pin-ended column
P_t	= tangent modulus load, the load at which bending of a perfectly straight column may commence
P_y	= axial load corresponding to yield point stress across entire section
r	= radius of gyration in the plane of bending
t	= flange thickness
w	= web thickness
x_0	= distance from the center of the elastic flange area to the beginning of the yielded area
y_0	= distance from the center of the plastic web area to the beginning of the elastic area
ϵ	= unit strain
σ_p	= proportional limit stress
$\sigma = P/A$	= applied average stress on a column
σ_{cr}	= critical stress
σ_{rc}	= residual stress at flange edges
σ_{rq}	= residual stress at flange centers
σ_{rw}	= residual stress at web center
σ_{rt}	= residual stress at web edges
σ_y	= yield stress level; average stress in the plastic range

$\sigma_{y(c)}$ = coupon yield stress level
σ_{uy} = upper yield point stress
σ_{rf} = residual stress in the flanges
σ_{rw} = residual stress in the web

APPENDIX 2: RECTANGULAR SPECIMEN CONTAINING RESIDUAL STRESS (AS REFERRED TO IN CHAPTER III, SECTION 1)

Figure 35 illustrates the action of a rectangular specimen under increasing load and shows the corresponding strain and the stress distributions. At $P = 0$ no load is applied and residual strains, only, are present in the specimen, Line (*b*). The distributions of Lines (*c*), (*d*), (*e*), (*f*) and (*g*) proceed in a straightforward manner. When the specimen is strained by loads P_1 to P_4 a uniform strain (Line (*c*)) must be added to the initial residual strain (Line (*b*)) to give the total strain (Line *d*). At P_2 the *total* stress has just reached the yield point, σ_y, at the edges. Stresses are still proportional to strains.

When the load reaches P_3, however, strains are greater than the elastic limit and the stress-diagram in Line (*e*) results. The superimposed stress, shown by Line (*f*), is determined simply by substracting the residual stress from the total stress distribution (Line (*e*)). P_3 is thus equal to the area cross-hatched in Line (*f*) times the thickness.

Finally at P_4 the cross section is completely yielded.

Sketch (*h*) of Fig. 35 shows a resultant stress-strain diagram for the whole specimen with certain critical points noted.* The column curve (including the influence of the assumed residual stress pattern) may be determined from the various yield and strain conditions. I_e in the equation for critical stress (eq 1) may be determined from the assumed yield condition.

If $k = x_0/(b/2)$,

$$\left.\frac{I_e}{I}\right|_x = k \qquad \text{(flexure about } x\text{-}x \text{ axis)}$$

$$\left.\frac{I_e}{I}\right|_y = k^3 \qquad \text{(flexure about y-y axis)}$$

P_{cr} is obtained from the stress condition (cross-hatched area of Line (*f*) of Fig. 35). For a *linear distribution of residual* stress,†

† If the flange is in equilibrium, $-\sigma_{rc} = +\sigma_{ro}$.

$$\sigma_{cr} = P_{cr}/A = \sigma_y - (1/2)(\sigma_{rc} - \sigma_{ro})(1 + k^2) - \sigma_{r_0}$$

For a *parabolic distribution of residual stress*,‡

‡ If the flange is in equilibrium, $-\sigma_{rc} = +2\sigma_{ro}$.

$$\sigma_{cr} = P_{cr/A} = \sigma_y - (1/3)(\sigma_{rc} - \sigma_{ro})(1 + 2k^3) - \sigma_{ro}$$

The critical L/r is then determined by solution of eq 1.

$$L/r|_x = \pi\sqrt{Ek/\sigma_{cr}}$$

$$L/r|_y = \pi\sqrt{Ek^3/\sigma_{cr}}$$

Sketch (*i*), Fig. 35, is the column curve that corresponds to the straight-line pattern. As is evident, a rather slight deviation from linearity of the stress-strain curve Fig. 35(*h*) has a pronounced influence on column strength.

* For illustration a 10-in. wide specimen of $\sigma_y = -40$ ksi and $-\sigma_{rc} = \sigma_{ro} = 20$ ksi was used. The dotted curve is for a parabolic distribution $-(\sigma_{rc} = 20$ ksi, $\sigma_{ro} = 10$ ksi).

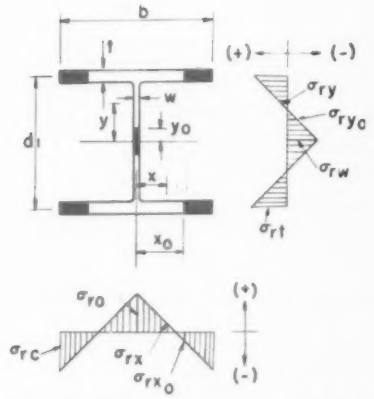


Fig. 36 Sketch of partially yielded cross section illustrating the nomenclature

APPENDIX 3

In this Appendix a solution is obtained for the influence of residual stress on WF columns, the solution being based on a known (or assumed) residual stress distribution and known yield stress level, σ_y.

A relationship between the average critical stress, σ_{cr}, and the yield condition (described by x_0) may be obtained by writing the equilibrium condition for forces in the axial direction of the column. Consider the residual stress distribution as illustrated in Figs. 41 and 36.* It is assumed that sufficient external load has

* The assumed residual stress distribution must be such that equilibrium is satisfied:

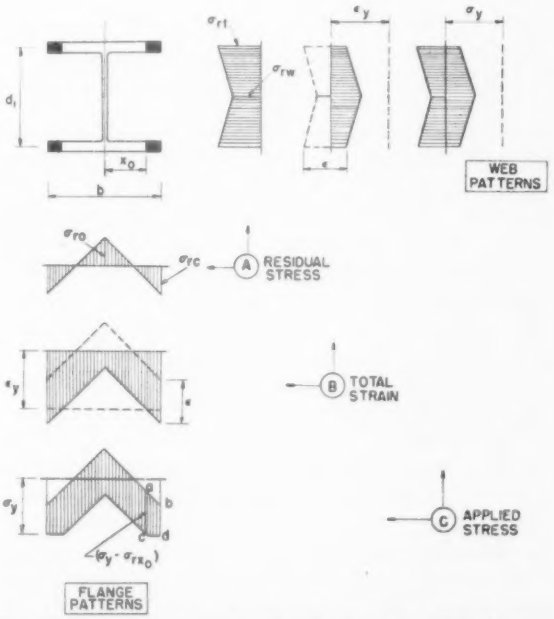


Fig. 37 Stress and strain distributions for WF shape—flange partially yielded

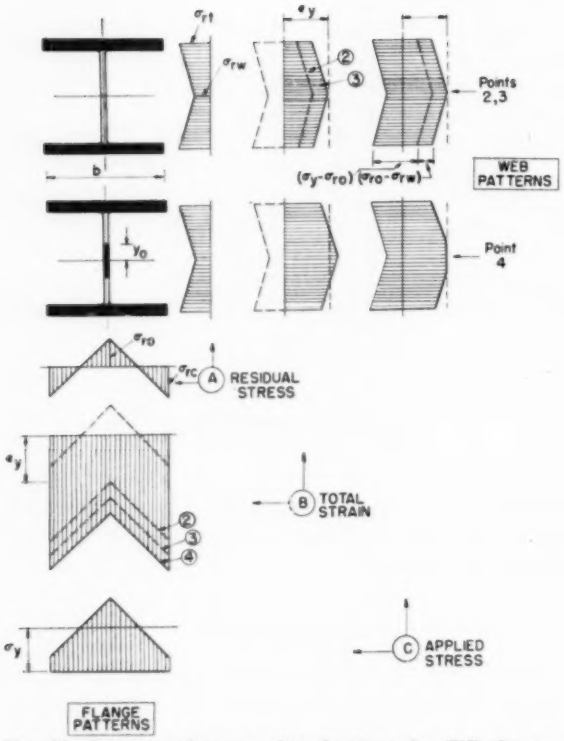


Fig. 38 Stress and strain distributions for WF shape—web partially yielded

$$\int_A \sigma_r dA = 4t \int_0^{b/2} \sigma_{rx}\, dx + 2w \int_0^{d_1/2} \sigma_{ry} dy = 0 \qquad (13)$$

been applied to cause yielding to occur at the areas cross-hatched. The meaning of the various symbols is indicated on the sketch. The applied load at the ends of the column causes a uniform stress distribution to be superposed on the existing residual stress pattern (Fig. 36). The edges of the flanges will reach the yield stress level when the applied uniform stress attains the value,

$$\sigma_p = P/A = \sigma_y - \sigma_{rc}$$

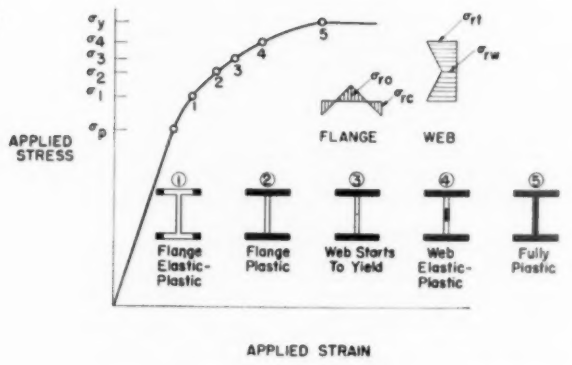
With further increase of the load a part of the flanges will yield and, depending on relative magnitudes of residual stresses in the flange and web, part of the web may also yield before the flanges have completely yielded. Thus, two possibilities must be considered:

(*a*) The web stays elastic until the flanges have completely yielded (Figs. 38 and 39).

(*b*) The web starts to yield before the flanges have completely yielded (Figs. 40 and 41).

First consider that only the flange edges are yielded (the load is slightly greater than $\sigma_p \times A$). A uniform strain, ϵ, is added to the existing residual strains (see Fig. 37). The resultant stress distribution is obtained as shown in Detail (C) by the same process as described in Appendix 2. The total force applied to the member is equal to the sum of the cross-hatched area in web and flanges, which corresponds to the applied or superimposed stress. The applied strain, ϵ, is given by

$$\epsilon_1 = (1/E)(\sigma_y - \sigma_{rx_0}) \qquad (14)$$



Stresses	*Strains*
$\sigma_p = \sigma_y - \sigma_{rc}$	$\epsilon_p = \frac{1}{E}(\sigma_y - \sigma_{rc})$
$\sigma_1 = \sigma_y - \frac{A_s}{A}\sigma_{rx_0} - \frac{4t}{A}\int_{x_0}^{b/2} \sigma_{rx}\, dx$	$\epsilon_1 = \frac{1}{E}(\sigma_y - \sigma_{rx_0})$
$\sigma_2 = \sigma_y - \frac{A_w}{A}\sigma_{r0} - \frac{4t}{A}\int_0^{b/2} \sigma_{rx}\, dx$	$\epsilon_2 = \frac{1}{E}(\sigma_y - \sigma_{r0})$
$\sigma_3 = \sigma_y - \frac{A_w}{A}\sigma_{rw} - \frac{4t}{A}\int_0^{b/2} \sigma_{rx}\, dx$	$\epsilon_3 = \frac{1}{E}(\sigma_y - \sigma_{rw})$
$\sigma_4 = \sigma_y - \frac{A_s}{A}\sigma_{ry_0} - \frac{4t}{A}\int_0^{b/2} \sigma_{rx}\, dx - \frac{2w}{A}\int_0^{y_0} \sigma_{ry}\, dy$	$\epsilon_4 = \frac{1}{E}(\sigma_y - \sigma_{ry_0})$
$\sigma_5 = \sigma_y$	$\epsilon_5 = \frac{1}{E}(\sigma_y - \sigma_{rt})$

Fig. 39 Idealized average stress-strain curve for WF shape containing residual stress—Case I

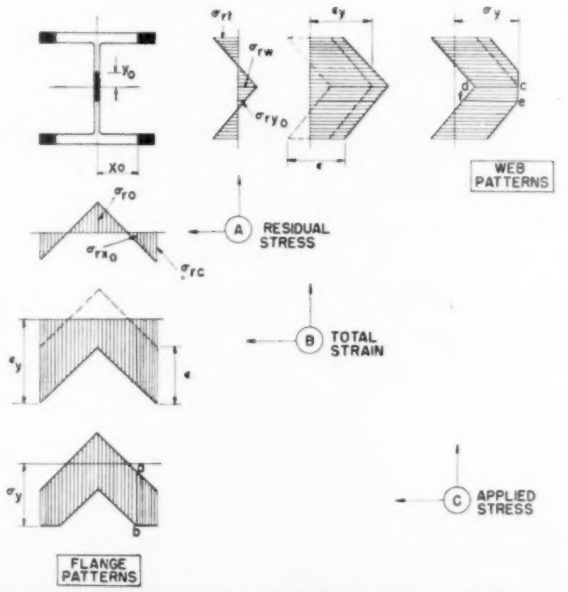
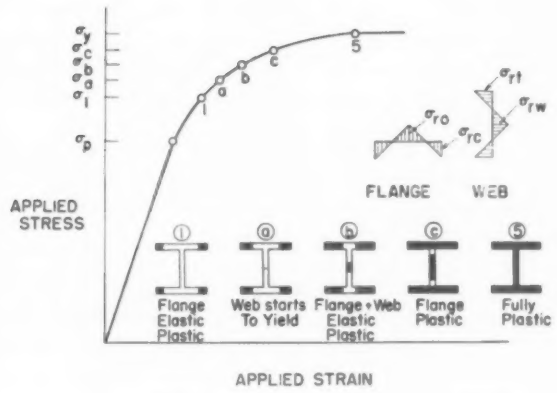


Fig. 40 Stress and strain distribution for WF shape—flange and web partially yielded



Stresses	*Strains*
$\sigma_p = \sigma_y - \sigma_{rc}$	$\epsilon_p = \frac{1}{E}(\sigma_y - \sigma_{rc})$
$\sigma_1 = \sigma_y - \frac{A_e}{A}\sigma_{rz_0} - \frac{4t}{A}\int_{x_0}^{b/2}\sigma_{rz}\,dx$	$\epsilon_1 = \frac{1}{E}(\sigma_y - \sigma_{rz_0})$
$\sigma_a = \sigma_y - \frac{A_e}{A}\sigma_{rw} - \frac{4t}{A}\int_{x_0}^{b/2}\sigma_{rz}\,dx$	$\epsilon_a = \frac{1}{E}(\sigma_y - \sigma_{rw})$
$\sigma_b = \sigma_y - \frac{A_e}{A}\sigma_{rz_0} - \frac{4t}{A}\int_{x_0}^{b/2}\sigma_{rz}\,dx - \int_0^{y_0}\sigma_{ry}\,dy$	$\epsilon_b = \frac{1}{E}(\sigma_y - \sigma_{rz_0})$
$\sigma_c = \sigma_y - \frac{A_e}{A}\sigma_{rw} - \frac{4t}{A}\int_0^{b/2}\sigma_{rz}\,dx - -\int_0^{y_0}\sigma_{ry}\,dy$	$\epsilon_c = \frac{1}{E}(\sigma_y - \sigma_{r0})$
$\sigma_b = \sigma_y$	$\epsilon_b = \frac{1}{E}(\sigma_y - \sigma_{rt})$

Fig. 41 Idealized average stress-strain curve for WF shape containing residual stress—Case II

The applied force in the flange is made up of a plastic part, ΔP_p, and an elastic part, ΔP_e. In the plastic part $\sigma_x = \sigma_y - \sigma_{rz}$. The stress in the elastic part corresponds to ϵ and is obtained at $x = x_0$ as being $\sigma_y - \sigma_{rz_0}$. In the web the stresses are all elastic and equal, also to $\sigma_y - \sigma_{rz_0}$. Therefore

$$P = \sigma A = \Delta P_p + \Delta P_e + \Delta P_{\text{web}}$$

$$P = 4t\int_x^{b/2}(\sigma_y - \sigma_{rz})\,dx + 4tx_0(\sigma_y - \sigma_{rz_0}) + wd_1(\sigma_y - \sigma_{rz_0})$$

or

$$P = 4t\int_{x_0}^{b/2}(\sigma_y - \sigma_{rz})\,dx + (\sigma_y - \sigma_{rz_0})(4tx_0 + wd_1)$$

The integral corresponds to the area $a - b - c - d$, in Fig. 37. Dividing P through by A, and using the relationship, $A_e = 4tx_0 + wd_1$ (the unhatched portion of cross section in Fig. 37).

$$\sigma_1 = \frac{P}{A} = \frac{4t}{A}\int_{x_0}^{b/2}(\sigma_y - \sigma_{rz})\,dx + \frac{A_e}{A}(\sigma_y - \sigma_{rz_0}) \qquad (15)$$

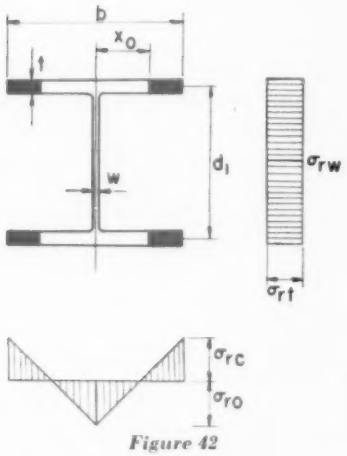


Figure 42

Simplifying the integral and rearranging terms the following expression is obtained for the applied stress just after first yielding has occurred.*

$$\sigma_1 = \frac{P}{A} = \sigma_y - \frac{A_e}{A}\sigma_{rz_0} - \frac{4t}{A}\int_{x_0}^{b/2}\sigma_{rz}\,dx \qquad (16)$$

The corresponding point on a typical stress-strain curve is shown in Fig. 39. Equations 9 and 10 also apply for a rectangular cross section if the corresponding A_e is taken.

There have now been obtained relationships between σ and x_0. To solve the problem posed by eq 1 in the text, a relationship must be found between I_e and the yield condition as described by the dimensions x_0 and y_0. This relationship is approximately as follows:

$$I_{ex} = x_0 t\left(d_1^2 + \frac{t^2}{3}\right) + \frac{w}{12}(d_1^3 - 8y_0^3)$$

$$I_{ey} = \frac{4t}{3}x_0^3 + \frac{w^3}{12}(d_1 - 2y_0) \qquad (17)$$

for the strong and weak axes respectively. Since both σ and I_e have been expressed in terms x_0 and y_0. it is now possible to solve eq 1 for L/r. A sample calculation is presented in Appendix 4.

APPENDIX 4: SAMPLE CALCULATION

Consider the distribution shown in Fig. 42. The flange stresses are

$$\sigma_{rz} = (2/b)(\sigma_{rc} - \sigma_{r0})\,x + \sigma_{ro} \qquad (18)$$

and the constant web stress follows from eq 13 (Appendix 3)

$$\sigma_{rw} = -\frac{bt}{wd_1}(\sigma_{rc} + \sigma_{ro}) \qquad (19)$$

The applied average stress for a partially plastic flange is obtained from eq 16 after substituting for σ_{rz_0} using eq 18. In terms of x_0 as the variable

$$\sigma = \sigma_y - \sigma_{ro} - \frac{\sigma_{rc} - \sigma_{ro}}{A}\left(\frac{4t}{b}x_0^2 + \frac{2wd_1}{b}x_0 + bt\right) \qquad (20)$$

* The sign convention is the usual one: compressive stresses negative, tensile stresses positive. Consistent with this convention, negative values are to be substituted for σ_y.

The question arises as to whether the web yields before the flanges are fully plastic. This may be determined from the condition that at yield of the web,

$$\sigma_{rx_0} = \sigma_{rw} \qquad \text{(see Detail } (c)\text{, Fig. 40)}$$

If σ_{r0} is less than σ_{rw} as determined from eq 19 then the flange is fully plastic before the web yields. Otherwise x_0, at which the web center becomes plastic, is determined from the condition that $\sigma_{rx_0} = \sigma_{rw}$.

For illustration consider a numerical example, using an 8 WF 31 shape

$\sigma_{rc} = -11$ ksi
$\sigma_{r0} = +5$ ksi
$\sigma_y = -39.8$ ksi
$E = 30{,}000$ ksi

Then from eq 18 $\sigma_{rx} = -4x + 5$, from eq 19 $\sigma = +9.4$ ksi and from eq 20 the average stress at a given x_0 is

$$\sigma = -38.8 + 0.964x_0 + 0.377x_0^2 \qquad (21)$$

Since $\sigma_{r0} < \sigma_{rw}$ the flanges will be completely plastic before the web reaches the yield point. (The average stress at this point is -38.8 ksi, only $2^1/_2\%$ lower than the yield stress level, indicating that the web is of little influence for this case.)

I_{cx} and I_{cy} are determined from eq 17 for the condition that $y_0 = 0$.

Thus, eq 1,

$$\sigma_{cr} = \frac{\pi^2 E I_c / I}{(L/r)^2}$$

may be solved for critical L/r by the use of eqs 17 and 21. It is advantageous to compute the column curves in tabular form, assuming successive values for x_0 from $b/2$ to 0:

The column curve of the above example is plotted in Fig. 32, Curve II.

Foil Seam Welding

by F. Busse

RESISTANCE seam welding has the disadvantage of an overlap. To avoid the overlap, a thin foil of steel can be inserted between the butted sheets and the wheels. The objection to the foil process has been the lack of contact resistance to bridge the butt gap completely. Foil welding was described in German Patent 369,901 filed in 1922 and issued in January 1926. It was not developed industrially until recently.

The foils F_1 and F_2 are shown in Fig. 1 between wheels R_1 and R_2 and the butted steel sheets I and II. In the absence of the foils all the current might be in one sheet without creating sufficient heat to fuse the sheets together. The foil serves as a bridge to distribute current to both sheets. To serve effectively as a bridge the foil must be centered accurately over the joint. The foil is usually 0.008 in. thick, $^1/_8$ to $^6/_{32}$ in. wide. The guides in Fig. 2 center the foil over the joint. The foil serves to prevent too rapid withdrawal of heat from the sheets. The contact resistance of the foil to the sheet is a minor factor, because no noticeable benefit is derived from using foils whose surface has been treated to produce high contact resistance.

The principal difficulty in foil welding is to fuse the butt to the edges, and not only at the middle, without using excessive power. Overheating injures the wheels, while underheating favors porosity in the middle of the weld. In ordinary lap seam welding the wheels must cool the surface of the sheets to prevent indentation. In foil welding, on the other hand, there must be fusion up to the surface of the sheets and the pressure must be low to avoid indentation. A modulator is best to supply current because there is no current zero during which the weld cools rapidly.

Pressure is required to assure good welding, Fig. 3. Clamps *SP* exert pressure *Pv* during welding. The clamping pressure *SP* is greater than the welding pressure *P*. The expansion caused by the welding heat is counteracted by the clamps, which thus exert pressure *Pv* indirectly. The clamps must be heavy and are a disadvantage. The joint also may be tacked beforehand, but this too is troublesome. The best system is to tack the foil to the sheets in a spot welder. Oxide must be removed from the tacks before foil welding. Magnetic clamping may be used.

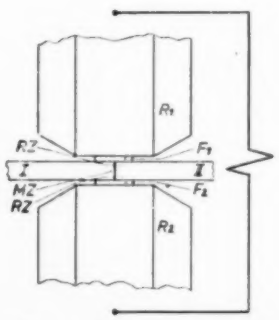


Fig. 1 Foil seam welding

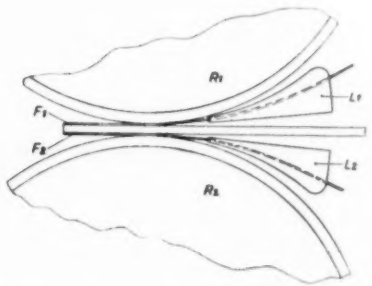


Fig. 2 Guided feed of foil. L_1 and L_2 are guides

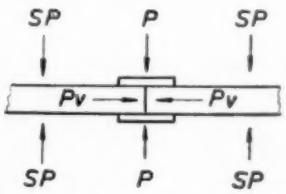


Fig. 3 Pressures in foil welding

PRACTICAL CONSIDERATIONS

The sheets must be of the same thickness and free from draw marks at the edges to be joined. The edges must be bright, absolutely free from oxide, and the gap must not exceed 0.012 in. The bright soft steel foil is 0.008 in. thick, $^6/_{32}$ in. wide and costs 0.05 marks per meter. Thinner or narrower foil is unnecessary. The maximum thickness of sheet that can be welded is $^6/_{32}$ in. Welding speeds for sheet 0.032 and 0.14 in. thick are 10 and $2^1/_2$ fpm, respectively. These speeds are the same as in usual lap seam welding with ignitron or modulator machines but are

Continued on page 624-s

Abstract of "Widerstandschweissen von Stahlblechen durch Folienstumpfnaht" published in *Schweissen und Schneiden*, 6, 248–253 (June 1954). (Abstracted by Dr. G. E. Claussen.)

Stresses from Radial Loads in Cylindrical Pressure Vessels

Design information on deflections, bending moments and membrane forces caused in cylindrical vessels by radial loads transmitted through various attachments

by P. P. Bijlaard

LOCAL forces transmitted to cylindrical pressure vessels through various attachments (nozzles, lugs, clips, etc.) often result in local stresses which cannot be neglected in design. This paper contains design information on deflections, bending moments and membrane forces caused in cylindrical vessels by radial loads uniformly distributed over a rectangular area $2c_1 \times 2c_2$ (Fig. 1). The cylindrical shell wall is assumed to be simply supported at the ends, which means that there the radial deflections, the bending moments and the tangential displacements are zero. The derivation of the equations from which this information was computed will be published separately in one of the journals suited for this purpose.[1] The data here published allow the direct determination of maximum stresses and deflections for design purposes. Comparison with the scattered, available test results reveals good agreement with the computed values. The content of this paper represents part of the results of a research project on Effects of External Loads on Pressure Vessels sponsored at Cornell University by the Pressure Vessel Research Committee of the Welding Research Council. Similar data for loadings by local longitudinal and circumferential moments will be published later.

DETERMINATION OF MOMENTS, FORCES AND DEFLECTIONS

Deflections, moments and forces are computed for the center 0 of the equally distributed load, which is applied at the middle of the vessel (Fig. 1). These results may also be used if the load is not at the middle of the vessel, as explained at the end of this section. In the case of a radial loading caused by a pipe or lug (Fig. 2*b*), the rigidity of the attachment will cause the stresses at B to be higher than those caused by uniform load at the same place B in Fig. 2*a*. However, they will probably be lower than those in point 0 in Fig. 2*a*. Therefore, to be conservative, the computed stresses at the center 0 of the uniformly distributed load should be considered as a reasonable approximation to the stresses at the edge of the attachment. In cases of load-

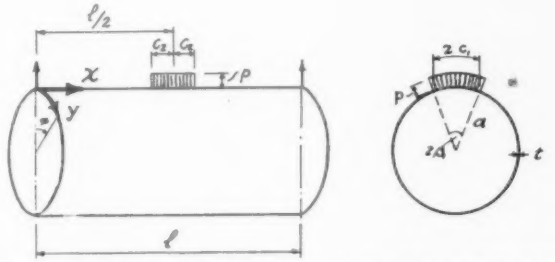


Fig. 1 Cylindrical shell loaded by a uniformly distributed radial load p within a rectangle ($2c_1$) ($2c_2$)

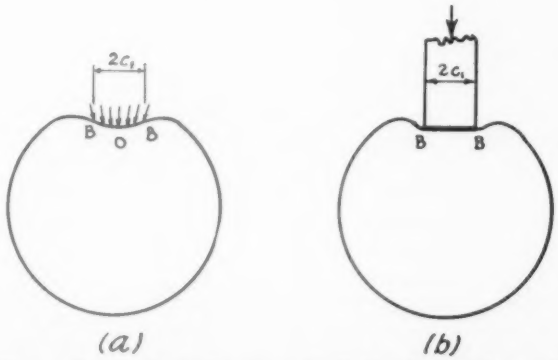


Fig. 2 Comparison of assumed radial loading and actual loading by pipe or lug

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This report has been prepared under the sponsorship of the Design Division of the Pressure Vessel Research Committee of the Welding Research Council.

ing by nonrectangular attachments such as nozzles the dimensions $2c_1$ and $2c_2$ of the loaded rectangle can be assumed as those of the rectangle or square circumscribing the actual attachment. For example, for a pipe with outer diameter D one chooses $2c_1$ and $2c_2 = D$.

The numerical data on which the design graphs, Figs. 5 to 9, are based were obtained by the use of IBM calculators from the author's equations.[1] These data are shown in Tables 1 and 2, which give the deflections w, the bending moments M_ϕ (circumferential) and M_x (longitudinal) and the membrane forces N_ϕ and N_x at the centers of the loads. The moments and membrane forces are given per unit width of shell wall. All values refer to a cylindrical shell (pressure vessel), simply supported at the ends and loaded in the center by a radial load P uniformly distributed over an area $2c_1$ x $2c_2$. The following designations are used:

$$\alpha = l/a, \qquad \gamma = a/t, \qquad \beta_1 = c_1/a \qquad \text{and} \qquad \beta_2 = c_2/a$$

From Fig. 1, l, a and t are the length, the radius and the thickness of the vessel, respectively.

It appears that for the ratios $\alpha = l/a$ considered, that is, $40 > \alpha > 3$, this ratio has little influence upon the bending moments and membrane forces. Also these values are mainly dependent on the area $4c_1c_2 = 4\,\beta_1\beta_2a^2$ over which the load is distributed and only partially on whether this area is a square ($\beta_1 = \beta_2$) or a rectangle ($\beta_1 \neq \beta_2$). Therefore graphs are given for the bending moments and membrane forces caused by loadings within square areas ($\beta_1 = \beta_2 = \beta$) and for a fixed ratio $\alpha = l/a = 8$. These graphs are those of Figs. 5, 6, 7 and 8.

They are based on the values in Tables 1 and 2, which are indicated by circles. The smaller β, the more laborious it is to evaluate the formulas in Reference 1. Therefore for small β values the graphs have been obtained by extrapolation, which was carried out down to dimensions of the loading square of $2c_1 = 2c_2 = 2c = 2\beta a = 3t$, or $\beta = 1.5/\gamma$. This extrapolation was possible, because it could be shown from the exact values of Tables 1 and 2 that the formula

$$(M_\phi \text{ or } M_x)_{\beta=\beta_b} = (M_\phi \text{ or } M_x)_{\beta=\beta_a} + AP \log (\beta_a/\beta_b) \quad (1)$$

can be used to find M_ϕ or M_x for a smaller ratio β_b from

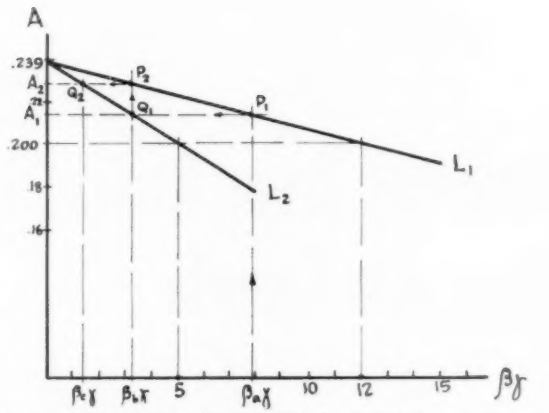

Fig. 3 Graph for finding A and β_b in order to compute M_ϕ from eq 1

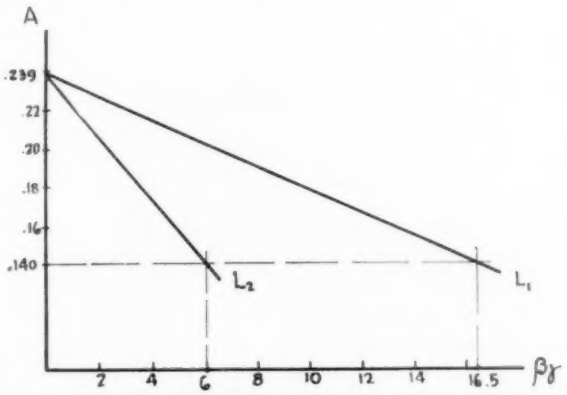

Fig. 4 Graph for finding A and β_b in order to compute M_x from eq 1

those for a larger ratio β_a. A and the relation between β_b and β_a are found from the straight lines L_1 and L_2 in Figs. 3 and 4, for M_ϕ and M_x, respectively. The coordinates in Figs. 3 and 4 are $\beta\gamma$ and A.

If, for example, M_ϕ is known for $\beta = \beta_a$ one enters Fig. 3 with $\beta\gamma = \beta_a\gamma$. This determines a point P_1 on line L_1. The coordinate $A = A_1$ of P_1 determines A in eq 1 and the intersection Q_1 of the horizontal line through P_1 with line L_2 determines the value $\beta_b\gamma$, which gives β_b to be used in eq 1. Hence eq 1 yields M_ϕ

Table 1

$\beta_1 = \beta_2 = 1/8$

$\gamma = a/t$	$\alpha = l/a$	*Point load,* $w/(P/Ea)$	*Distributed load* $w/(P/Ea)$	M_ϕ/P	M_x/P	$-N_\phi/(P/a)$	$-N_x/(P/a)$
15	3	300	272	0.1324	0.1057	2.6125	2.3200
	6	468	442	0.1438	0.1100	2.5920	2.6400
	10	601	576	0.1463	0.1102	2.5744	2.784
50	3	4,352	3,645	0.0863	0.0559	6.4512	7.120
	8	7,631	6,924	0.0967	0.0614	6.4816	8.064
	20	13,430	12,930	0.1030	0.0634	6.4336	8.704
100	3	20,227	15,800	0.0626	0.0343	9.5776	12.784
	8	34,350	30,136	0.0716	0.0394	9.7920	14.192
	30	74,379	71,448	0.0767	0.0400	9.6176	15.472
300	3	231,738	158,362	0.0337	0.0137	13.6960	29.328
	8	402,590	313,842	0.0406	0.0172	14.9632	32.288
	20	625,855	566,530	0.0440	0.0180	14.5840	33.424
	40	968,910	925,438	0.0453	0.0180	14.2000	34.128

Table 2

$\gamma = \alpha/t$	$\alpha = l/a$	β_1	β_2	*Point load,* $w/(P/Ea)$	*Distributed load* $w/(P/Ea)$	M_ϕ/P	M_x/P	$-N_\phi/(P/a)$	$-N_x/(P/a)$
15	8	1/4	1/4	509	423	0.0773	0.0485	1.8196	2.2316
50	8	1/4	1/4	7,628	5,693	0.0439	0.0191	3.1228	5.9652
100	8	1/4	1/4	34,345	23,707	0.0291	0.0106	3.6756	9.3812
100	8	1/32	1/32	34,345	34,233	0.2003	0.1519	30.0032	18.6624
100	8	1/4	1/16	34,345	24,827	0.0355	0.0305	11.1872	10.5536
100	8	1/16	1/4	34,345	30,322	0.0805	0.0284	4.9088	12.8720
100	3	1/4	1/16	20,227	11,537	0.0285	0.0278	11.0976	9.1616
100	3	1/16	1/4	20,227	15,830	0.0729	0.0275	5.0960	11.5408
300	8	1/4	1/4	402,590	227,971	0.0140	0.0045	3.7132	17.7316
300	8	1/32	1/32	402,590	391,568	0.1503	0.1019	48.6144	53.5808

for $\beta = \beta_b$. In the same way, from M_ϕ for $\beta = \beta_b$ one can find M_ϕ for $\beta = \beta_c$, using $A = A_2$ as shown in Fig. 3, etc. In this way values M_ϕ for $\beta = \beta_b$, $\beta = \beta_c$, etc., are found, so that the graph for M_ϕ could be extrapolated to smaller β values. The same applies to M_x using Fig. 4.

The graphs for N_ϕ could be extrapolated to smaller β values, since it was found that for constant α and γ, N_ϕ can be represented as

$$N_\phi = pa\,(1 - e^{-F}\cos F) \qquad (2)$$

where $F = C_1\beta^2 + C_2\beta^3 + C_3\beta^4$. From the values in Tables 1 and 2 the parameters C_1, C_2, C_3 were calculated. The graphs for N_x were extrapolated in a similar way.

Corrections for length/radius-ratios other than 8 may be made by using Fig. 9, which is based upon Table 1; it involves the assumption that the variation of the moments and membrane forces with α for β values other than 1/8 is the same as for $\beta = 1/8$. After having found from Figs. 5 to 8 the moments or membrane forces for $\alpha = 8$, Fig. 9 gives the percentage of these values which has to be used for ratios α other than 8.

Although Figs. 5 to 8 are drawn for square load areas, they can be used for rectangular load areas in the following manner: By comparing the bending moments and membrane forces for rectangular loading, i.e., for $\beta_1 = 1/4$, $\beta_2 = 1/16$, $\gamma = 100$, $\alpha = 8$ in Table 2 with those for square loading and for the same $\gamma = 100$, $\alpha = 8$ in Figs. 5, 6, 7 and 8, one finds that the values for rectangular loading areas are equal to those for square areas ($\beta_1 = \beta_2 = \beta$) when $\beta = K_1\sqrt{\beta_1\beta_2}$, where K_1 is given in Table 3. This holds for rectangles with the short side parallel to the axis of the vessel. For the converse case, i.e., for $\beta_1 = 1/16$, $\beta_2 = 1/4$ the loadings cause the same values of M_ϕ, M_x, N_ϕ and N_x as square areas when $\beta = K_2\sqrt{\beta_1\beta_2}$. The values of K_2 are also given in Table 3. For rectangles with side ratios other than 1:4, that is, for any $\beta_1\beta_2$ combination, one may approximately find the moments and membrane forces from Figs. 5, 6, 7 and 8 by assuming square loading areas with $\beta(= \beta_1 = \beta_2) = K\sqrt{\beta_1\beta_2}$ where:

$$\left.\begin{aligned} &\text{for } \beta_1/\beta_2 > 1: \quad K = 1 - \frac{(\beta_1/\beta_2) - 1}{3}\,(1 - K_1) \\ &\text{for } \beta_1/\beta_2 < 1: \quad K = 1 - \frac{1 - (\beta_1/\beta_2)}{0.75}\,(1 - K_2) \end{aligned}\right\} \qquad (3)$$

This approximation holds within the limits $4 \geq \beta_1/\beta_2 \geq 0.25$, which will cover most practical cases.

If the rectangular attachment is of small rigidity the possibility exists that the load is actually more closely distributed within a square with sides equal to the smaller dimensions of the rectangle. In this case it is safer to assume β equal to c_1/a or c_2/a, where $2c_1$ or $2c_2$ are the smaller dimensions of the rectangle, respectively.

The graph may also be used for off-center radial loadings, applied at an arbitrary distance x from the left end of the vessel (Fig. 1). The deflections, bending moments and membrane forces may be assumed to be equal to those for an equivalent vessel, loaded at the middle, with an equivalent length $l_{eq} = 4\,x\,(l - x)/l$, so that in Fig. 9 one has to determine the ratio α as l_{eq}/a.

The details of using the charts of Figs. 5 to 9 for obtaining stresses and deflections of vessels of specified dimensions are shown in the next section, in connection with a comparison of theory with available test results.

Table 3

For Rectangular Loadings—Sides Ratio 1:4

	M_ϕ	M_x	N_ϕ	N_x	*Remarks*
K_1	1.76	1.2	0.91	1.68	Short side parallel to axis
K_2	0.88	1.25	1.48	1.2	Long side parallel to axis

DIMENSIONS OF REINFORCING PADS

If the stresses around the attachment, with dimension $(2c_1)$ $(2c_2)$ are too large, the shell has to be reinforced by an extra plate. This introduces the problem of determining the required dimensions $(2d_1)$ $(2d_2)$ of the reinforcing plate in such a way that the stresses at its boundaries are below permissible limits (Fig. 10). As suggested by Professor George Winter, a simple method for determining these stresses would be to consider the reinforcing plate as a rigid lug or clip, so that the moments and membrane forces can be found directly from the graphs of Figs. 5–9, as shown above. For a given load one can then determine the size of the loaded area which would result in stresses of permissible magnitude. The required reinforcing pad has the size of the area so determined. This method will generally

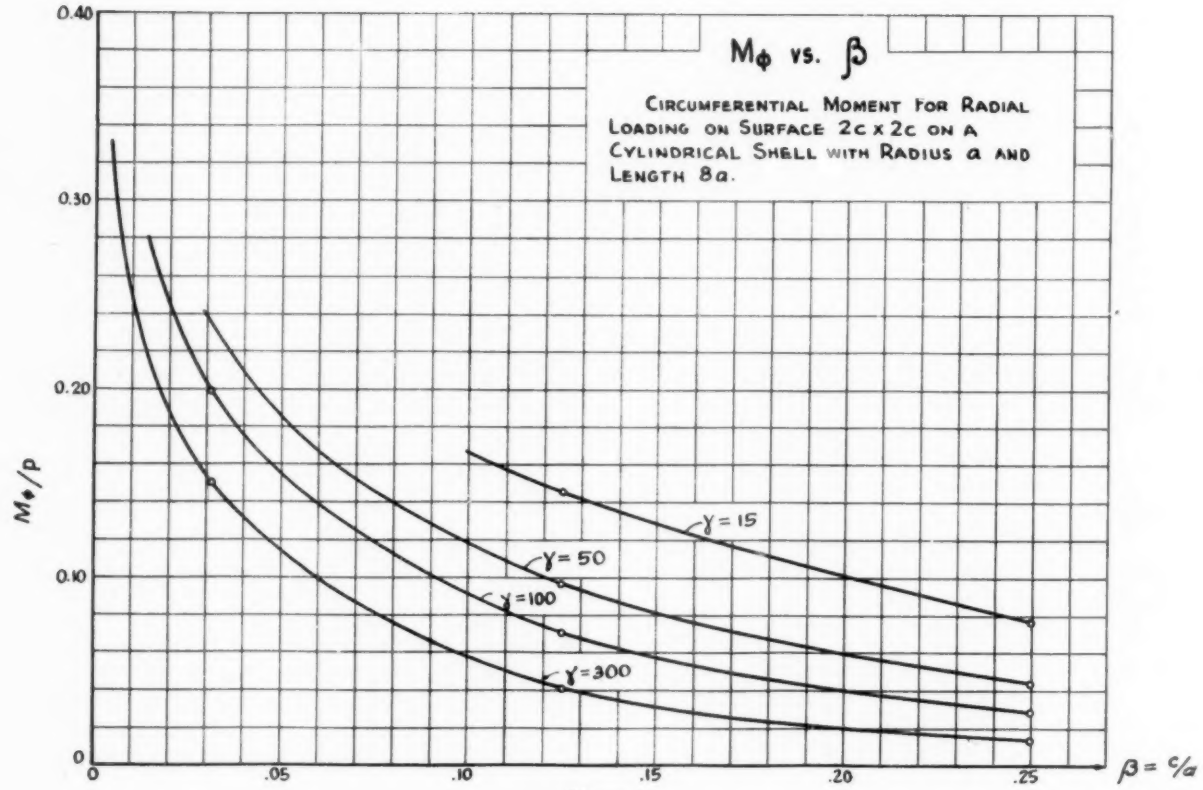

Figure 5

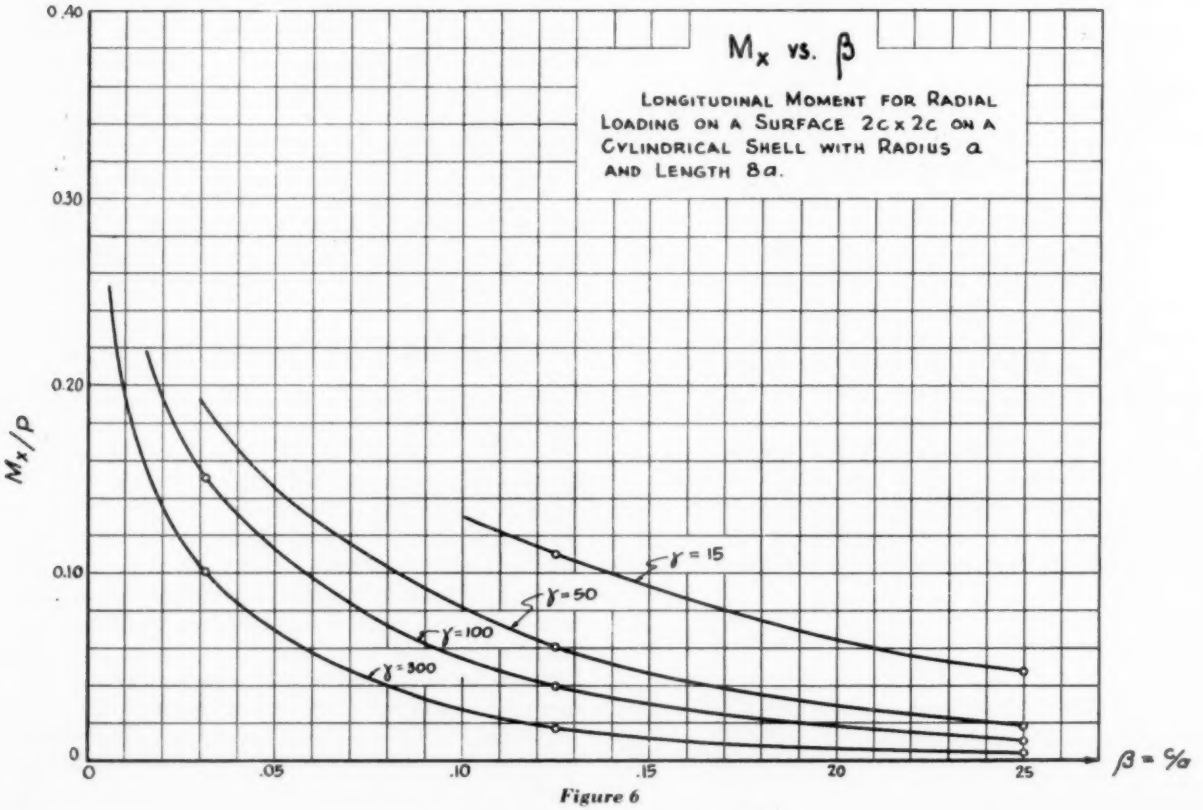

Figure 6

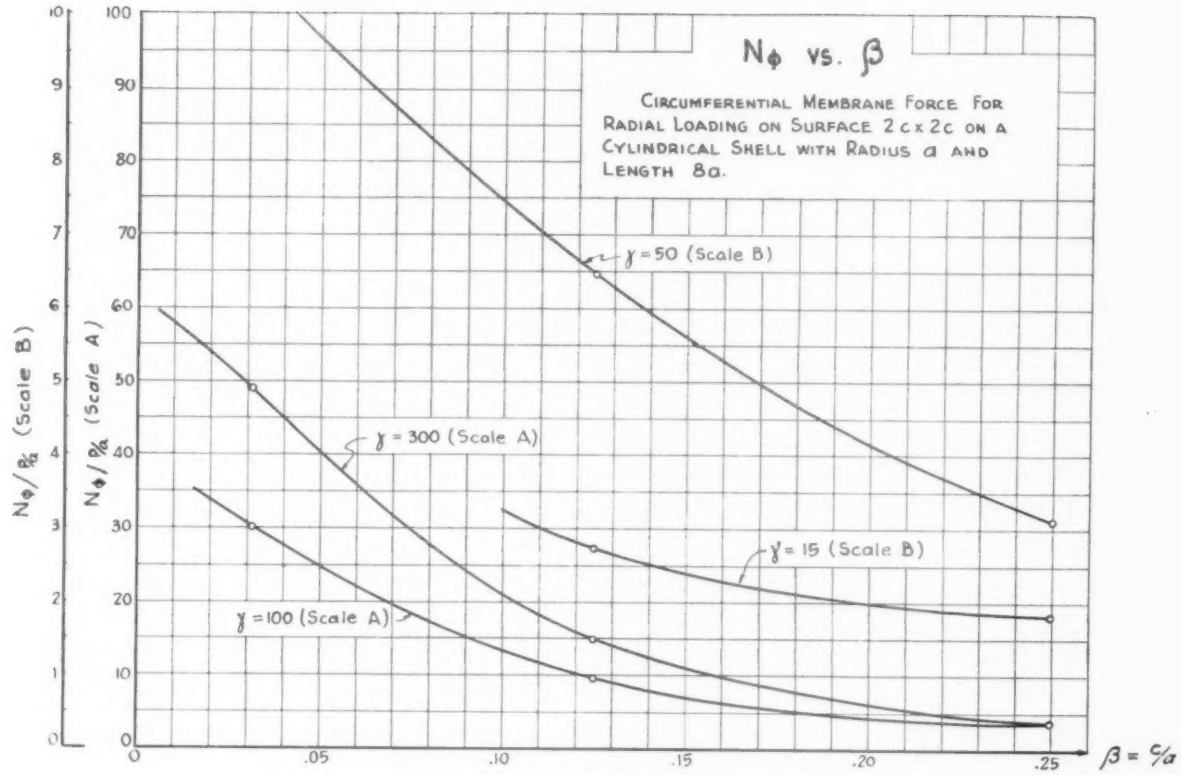
N_ϕ vs. β
Circumferential Membrane Force For Radial Loading on Surface 2c x 2c on a Cylindrical Shell with Radius a and Length 8a.
γ = 50 (Scale B)
γ = 300 (Scale A)
γ = 15 (Scale B)
γ = 100 (Scale A)
N_ϕ/P_a (Scale B)
N_ϕ/P_a (Scale A)
$\beta = c/a$

Figure 7

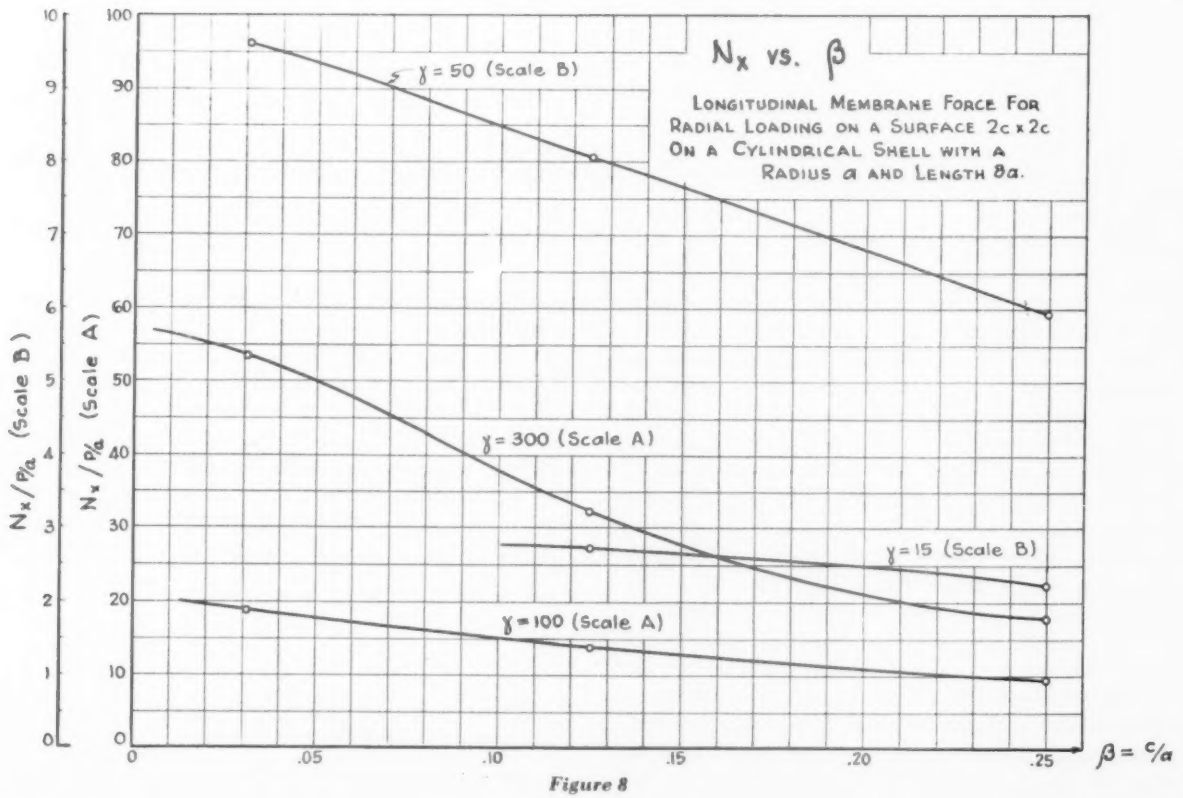
N_x vs. β
Longitudinal Membrane Force For Radial Loading on a Surface 2c x 2c On a Cylindrical Shell with a Radius a and Length 8a.
γ = 50 (Scale B)
γ = 300 (Scale A)
γ = 15 (Scale B)
γ = 100 (Scale A)
N_x/P_a (Scale B)
N_x/P_a (Scale A)
$\beta = c/a$

Figure 8

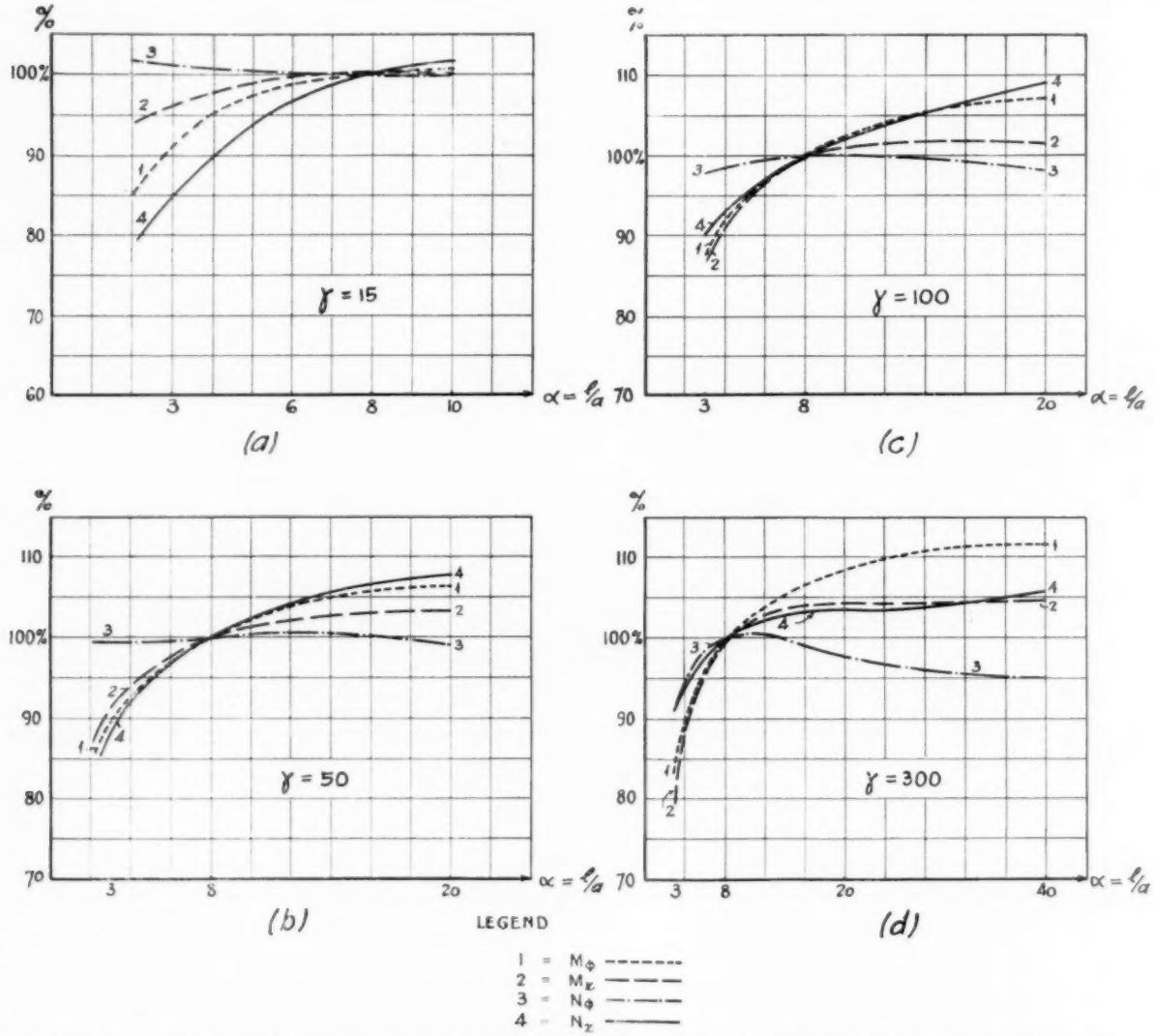

Fig. 9 Graphs for finding moments and membrane forces for ratios l/a other than 8 from those for l/a = 8

be conservative. A more elaborate but more accurate and economical method is the following:

Since the double series formulas were evaluated numerically only for the maximum values under the center of the load, no direct data are available for finding the accurate values of the stresses at the edges of the reinforcing plate. Moreover these formulas apply for a shell of constant thickness only, so that they would not take account of the higher local rigidity of the shell due to the reinforcement. However, by comparing the effect of a loading within a square $(2c)$ $(2c)$ with that of a loading within an infinitesimally larger square $(2c + dc)$ $(2c + dc)$, it is possible to determine the influence of the difference between these loadings, that is of a loading on the area $8cdc$ along the edges of the square, upon the stresses in the center of the square. Inversely from this a method can be found for determining the moments at a given distance from the center of the loading surface, which could be checked by comparison with test results by Roark.[3] The edge stresses will obtain maximum values at the midpoints A and B in Fig. 10. For the moment M_ϕ at B, at distance d_2 from the load center (Fig. 10), it is sufficiently accurate to consider the reinforcing plate as a rigid attachment. Membrane forces at A and B may be similarly treated since their influence on the total stress is relatively small. This leads to the following formulas for the moments: M_ϕ at A, at a distance d_1 from 0 in the $y(\phi)$ direction, is

$$M_\phi = \frac{c_1}{2d_1 - c_1}(M_\phi)_{d_1 2} + 0.8\,\psi\,\frac{2(d_1 - c_1)}{2d_1 - c_1}(M_\phi)_{d_1 r} \quad (4)$$

where the subscript r refers to "reduced." M_ϕ at B, at a distance d_2 from 0 in the X-direction, is

$$M_\phi = (M_\phi)_{d_2} \quad (5)$$

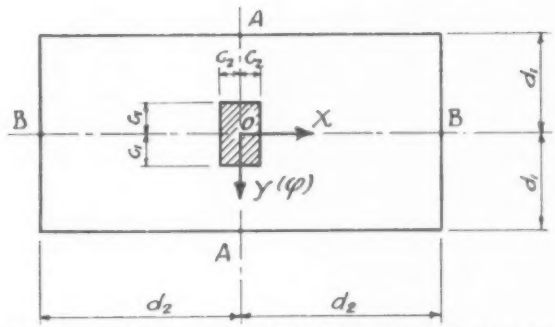

Fig. 10 Loading surface ($2c_1$) ($2c_2$) and reinforcing pad ($2d_1$) ($2d_2$)

M_x at A, at a distance d_1 from 0 in the ϕ-direction, is

$$M_x = \frac{c_1}{2d_1 - c_1}(M_x)_{d12} + 1.3\,\psi\,\frac{2(d_1 - c_1)}{2d_1 - c_1}(M_x)_{d1r} \quad (6)$$

M_x at B, at a distance d_2 from 0 in the X-direction, is

$$M_x = \frac{c_2}{2d_2 - c_2}(M_x)_{d12} + \psi\,\frac{2(d_2 - c_2)}{2d_2 - c_2}(M_x)_{d2r} \quad (7)$$

Further, as stated above, N_ϕ and N_x are found from the graphs of Figs. 7–9 by considering the reinforcing plate as a rigid lug.

In these formulas the moments in the first terms, with subscripts d_{12}, are calculated by considering the reinforcing plate as a rigid lug, with dimensions d_1 and d_2, as shown in the preceding section. The moments in the second terms, with subscripts $d1r$ or $d2r$ are

$$(M_{\phi \text{ or } x})_{d(1 \text{ or } 2)r} = 2(M_{\phi \text{ or } x})_{d(1 \text{ or } 2)} - M'_{\phi \text{ or } x} \quad (8)$$

where $(M_{\phi \text{ or } x})_{d(1 \text{ or } 2)}$ is $M_{\phi \text{ or } x}$ from the graphs of Figs. 5 or 6 for $\beta = d_1/a$ or d_2/a (Fig. 11) and $M'_{\phi \text{ or } x}$ is found from these graphs as indicated in Fig. 11. That is,

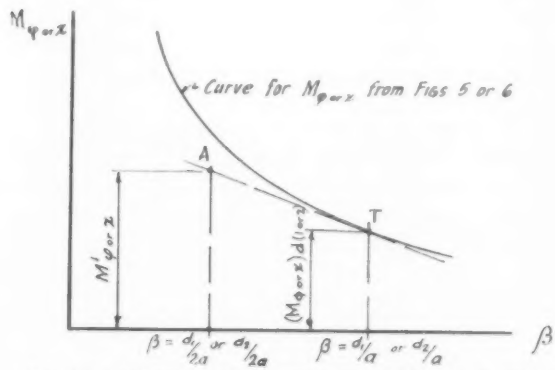

Fig. 11 Indication of the meaning of $M'_{\phi \text{ or } x}$ in eq 8

a straight line TA is drawn tangent to the graph at T and the moment $M'_{\phi \text{ or } x}$ is measured up to this line TA at $\beta = (1/2)d_1/a$ or $(1/2)d_2/a$. Further, in eqs 4 to 7,

$$\psi = \frac{(M_{\phi \text{ or } x})_{\text{rect.}}}{(M_{\phi \text{ or } x})_{\text{square}}} \quad (9)$$

where the subscript "rect" means that M_ϕ or M_x are the maximum moments for a load within the rectangular loading surface ($2c_1$) ($2c_2$), calculated by using eq 3 as shown in the preceding section. For determining the moments at A or B, $(M_{\phi \text{ or } x})_{\text{square}}$ is the maximum moment for a load within a square loading surface with sides equal to the sides of the load rectangle parallel to A-A or B-B, respectively. Hence for determining the moments at A the square is $(2c_1)^2$ and for moments at B it is $(2c_2)^2$.

In this manner moments and membrane forces in the shell at points A and B at the edge of the reinforcing pad can be found. If the resulting stresses in the shell at A and B are larger than permissible, a larger plate must be used. Consequently, the final size of the reinforcement must be established by successive trials. To shorten the procedure it is convenient to establish the first trial dimensions by the simple method suggested by Professor George Winter and described above. Since this method is conservative, the next trial is started with a somewhat smaller pad and eqs 4 to 9 are used.

COMPARISON WITH TEST RESULTS

Tests by Schoessow and Kooistra

Results of radial compression tests are given in Fig. 7 and Table 2 of Reference 2. Although in these tests two equal and opposite loads were applied at the ends of one diameter instead of the single load considered in this paper, the stresses for both cases should not appreciably differ.

For the *thin cylinder* tested by Schoessow and Kooistra

$$\alpha = l/a = 71''/28'' = 2.536$$
$$c = 11.75''/2 = 5.875''$$
$$\beta = c/a = 5.875''/28'' = 0.21$$
$$\gamma = a/t = 28''/1.3'' = 21.54$$

From Fig. 6, which is drawn for $\alpha = 8$, one finds, with $\gamma = 50$ and $\beta = 0.21$: $(M_x)_{\alpha=8} = 0.028P$. Using Fig. 9 this value is corrected for $\alpha = 2.536$, which yields $M_x = 0.8925(M_x)_{\alpha=8} = 0.025P$. Further, from Fig. 6, for $\gamma = 15$ and $\beta = 0.21$, one finds $(M_x)_{\alpha=8} = 0.060P$. Correcting this for $\alpha = 2.536$ one finds from Fig. 9, $M_x = 0.95(M_x)_{\alpha=8} = 0.57P$. Hence for $\gamma = 21.54$, interpolating between $M_x = 0.025P$ for $\gamma = 50$ and $M_x = 0.057P$ for $\gamma = 15$, one obtains $M_x = 0.051P$. Since the test load was $P = 94{,}900$ lb., this yields $M_x = 4842$ *in.-lb/in.* In the same way one finds from Fig. 8, for $\alpha = 8$, $\gamma = 50$ and $\beta = 0.21$: $(N_x)_{\alpha=8} = -6.6P/a$. From Fig. 9, for $\alpha = 2.536$: $N_x = 0.855\,(N_x)_{\alpha=8} = -5.643P/a$. From Fig. 8, for $\alpha = 8$, $\gamma = 15$ and $\beta = 0.21$: $(N_x)_{\alpha=8} = -2.45P/a$. From Fig. 9, for $\alpha = 2.536$: $N_x = 0.820(N_x)_{\alpha=8} = -2.01P/a$. Hence for $\gamma = 21.54$, interpolating between $N_x = -5.643P/a$ for $\gamma = 50$ and $N_x = -2.01P/a$ for $\gamma = 15$, one obtains $N_x = -2.688P/a = -2.688\,(94{,}900/28) = -9110$ *lb/in.*

The stress at the outside of the vessel becomes

$$\sigma_x = -\frac{6M_x}{t^2} + \frac{N_x}{t} = -17,189 - 7007 =$$

$$-24{,}200 \text{ psi}.$$

It was pointed out that this calculated stress applies to the center point of the uniformly loaded surface (point 0 of Fig. 2*a*) and that it is suggested to assume the stress at the edge of a rigid attachment (point *B*, Fig. 2*b*) to be of the same magnitude.* In the tests the load was transmitted by means of a pipe, corresponding to Fig. 2*b*. In the present case the ratios of the thicknesses of pipe and shell and that of their diameters is such that the attachment may indeed be assumed to be practically rigid. Since strain gages could not be applied directly at the junction, one set of gages was placed as close to it as possible, and others at increasing distances from the pipe. To obtain the probable value of the stress directly at the junction one has to extrapolate this experimental stress distribution to the intersection of pipe and shell. This has been done and a value of about $\sigma_x = -24{,}000$ psi has been obtained, which is in excellent agreement with the computed value.

In the same way one finds from the graphs $M_\phi = 7456$ in.-lb/in., $N_\phi = -7986$ lb/in. and $\sigma_\phi = -52{,}610$ *psi*. From Fig. 7 of Reference 2 one obtains, by extrapolating, a maximum measured stress σ_ϕ of about $-31{,}000$ psi.

Similarly one finds for the *thick cylinder* of the Schoessow and Kooistra tests that the calculated stresses at the outside of the vessel are $\sigma_x = -10{,}500$ psi, $\sigma_\phi = -14{,}550$ psi. From Fig. 7 and Table 2 of Reference 2 the extrapolated test results yield maximum stresses $\sigma_x = -10{,}000$ psi, $\sigma_\phi = -12{,}000$ psi, in satisfactory agreement with the theoretical values.

Tests by Roark

In these tests equal and opposite concentrated compressive loads were applied at the ends of one diameter from the inside. Actually the load, which was transferred by rods with semispherical ends, is distributed over a finite area. Although for a point load the theory of thin shells does not strictly apply, valid data can be obtained by assuming the load distributed over a larger finite area, as a consequence of the finite thickness of the shell.

From Fig. 4 and eq 5 of Reference 3 it can be shown that Roark assumes that for both his thin and thick steel cylinders the radius b of the circular area over which the concentrated load is distributed is equal to $0.00458a$. It may then be assumed sufficiently accurate that $\beta = c/a = 0.00458$. (It may be remarked that actually β is probably larger for the thick than for the thin cylinder.)

* The designer is cautioned that this assumption is not valid if the ratio of thicknesses of pipe and shell and that of their diameters is not in step; hence the applicability of this analysis may be considerably in error if the nozzle is considerably less rigid than the portion of the shell cut out. This may be the case when dealing with thin wall connections attached to thick wall vessels.

Considering first the *thin steel cylinder*, where $\gamma = a/t = 11.5''/0.129'' = 89.15$, values M_x and M_ϕ for $\beta = 0.00458$ may be obtained from the values at the left ends of the graphs for M_x and M_ϕ (Figs. 5 and 6), by extrapolating these graphs to the left, using eq 1 and Figs. 3 and 4, as explained above. Further N_x and N_ϕ were obtained by drawing a tangent to the left ends of the curves in Figs. 7 and 8. This gives for $\beta = 0.00458$ and $\alpha = 8$, interpolating between the values for $\gamma = 50$ and $\gamma = 100$, for $\gamma = 89.15$:

$$M_x = 0.3497P$$
$$N_x = -16.77P/a$$
$$M_\phi = 0.3967P$$
$$N_\phi = -32.64P/a$$

The test load $P = -120$ lb. Hence the maximum calculated tensile stresses under the load, at the outside of the tube, are:

$$\sigma_x = \frac{0.3497 \times 120 \times 6}{(0.129)^2} + \frac{16.77 \times 120}{11.5 \times 0.129} = 16{,}500 \text{ psi}$$

$$\sigma_\phi = \frac{0.3967 \times 120 \times 6}{(0.129)^2} + \frac{32.64 \times 120}{11.5 \times 0.129} = 19{,}900 \text{ psi}$$

These stresses apply for $\alpha = l/a = 8$ for which Figs. 5 to 8 are drawn. For Roark's cylinder $\alpha = 120/11.5 = 10.4$, but his cylinder was open at the ends, so that the cases are not quite similar. He finds, by estimating the maximum stress to be 1.5 times that measured for $^1/_2$ in. gage length, $\sigma_x = 13{,}400$ psi, $\sigma_\phi = 16{,}500$ psi, as may be read from his Figs. 4 and 5.

In the same way one finds for the tested thick steel cylinder, from the graphs, for $P = 620$ lb, $\alpha = 8$, $\gamma = 11.75''/0.33'' = 35.606$ and $\beta = 0.00458$, calculated values $\sigma_x = 15{,}080$ psi and $\sigma_\phi = 17{,}000$ psi, while the estimated values from Roark's tests are $\sigma_x = 14{,}000$ psi and $\sigma_\phi = 16{,}600$ psi from his Figs. 4 and 5.

From Fig. 10 of Reference 3 the maximum measured deflection of the thin steel cylinder, using two opposite loads $P = 120$ lb, was $w = 0.0130$ in. From Table 1 of the present paper one finds by interpolation, for $\gamma = a/t = {}^{11.5}/_{0.129} = 89.15$ and $\alpha = l/a = 120/11.5 = 10.4$ and for a single concentrated load, $w = 0.0113$ in. This value is obtained by subtracting from the total deflection the simple beam deflection, since in Roark's tests with two equal and opposite loads the beam deflection is evidently zero.

The above agreement between computed and measured values is as good as can be expected.

INFLUENCE OF INTERNAL OR EXTERNAL PRESSURE

In Reference 1 formulas were also developed to account for the effect of internal or external pressure. Until these formulas have been numerically evaluated it can only be said that in the case of internal pressure a conservative result is obtained if the stresses caused by pressure are simply added to those caused by local loadings as calculated above. At the same time in the case of external pressure the same procedure leads to

inconservative results. As a matter of fact, a concentrated load applied to a vessel subjected to external pressure may weaken the vessel considerably if its strength is governed by the danger of buckling.

ACKNOWLEDGMENT

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The numerical values on which the charts of Figs. 5 to 9 are based were calculated on IBM machines. Part of this work was done on a CPC type calculator at Cornell Aeronautical Laboratory under the direction of Dr. A. Blake. About half of this work was a donation of Cornell Aeronautical Laboratory. The other part was done on a 701 type calculator under the direction of Dr. Walter Murdock of IBM. To save computing costs somewhat simplified formulas were used for the machine calculations. The results were subsequently corrected on desk calculators at Cornell University for the influence of the neglected terms. This was done mostly by Mohammad Y. Lalee and partly by Fouad A. R. Osman, both graduate students at Cornell University.

The author wishes to express his appreciation for the valuable cooperation of all concerned. He also would like to thank his colleague Prof. George Winter for his suggestion to find a method for determining the required dimensions of reinforcing pads.

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Nomenclature

a	=	radius of cylindrical shell.
c	=	half length of square loading surface.
c_1	=	half length of rectangular loading surface in the circumferential direction.
c_2	=	half length of rectangular loading surface in the longitudinal direction.
d_1	=	half length of reinforcing pad in the circumferential direction.
d_2	=	half length of reinforcing pad in the longitudinal direction.
l	=	length of shell.
t	=	wall thickness of shell.
w	=	radial deflection.
x	=	coordinate in longitudinal direction of shell.
y	=	coordinate in circumferential direction of shell.
E	=	modulus of elasticity.
K	=	coefficient given by eqs 3.
K_1, K_2	=	coefficients given in Table 3 and used in eqs 3
M_ϕ, M_x	=	bending moments in shell wall in the circumferential and longitudinal direction, respectively.
N_ϕ, N_x	=	membrane forces in shell wall in the circumferential and longitudinal direction, respectively.
P	=	concentrated radial load or total distributed radial load.
α	=	l/a.
β	=	c/a.
β_1	=	c_1/a.
β_2	=	c_2/a.
γ	=	a/t.
ϕ	=	cylindrical coordinate in circumferential direction of shell.
σ_ϕ	=	stresses in the circumferential direction.
σ_x	=	stresses in the longitudinal direction.

Admiralty Ship Welding Reports

THE Admiralty Ship Welding Committee, in its study of the special problems arising from the use of welding in ships' structures, has carried out a program of investigations to compare the structural behavior of welded and riveted ships under the loadings experienced at sea. For the reasons stated in Report R.8, and in the light of the information obtained from its earlier still water structural tests, the Committee decided that the most promising approach to this problem would be to proceed with a series of trials in three stages, which may be briefly summarized as follows:

Report 6—Investigation of the stress response of two sister ships, the welded *Ocean Vulcan* and the riveted *Clan Alpine* under various states of loading in still water.

Report 7—Investigation of the loads imposed on one of these ships, the *Ocean Vulcan*, under prolonged periods of sea service.

Report 11—Application of the results of the still water experiments to the estimation of probable maximum loads derived from the sea trials, in order to estimate the probable maximum stresses at sea for both the welded and riveted ships.

Report No. 6 describes an investigation of the stress response of the welded cargo ship *Ocean Vulcan*, under various conditions of loading in still water. These conditions, which were obtained by flooding ballast tanks and holds, were so arranged that they could be directly related to the various actions to which a ship is subjected at sea.

The preparation of the ship for the experiments and the conditions existing at the anchorage are described. Details of the various loading conditions and methods of calculating moments of inertia and bending moments are given in separate Tables. The results are presented

in diagrammatic form, accompanied by a brief description in the text. Particular attention has been paid to the changes in stresses near amidships due to the changes in loading, as well as to vertical and horizontal deflections and to local bending of certain panels of plating and to the stress distributions at structural details.

CONCLUSIONS

Main Hog-Sag Cycle

1. Within the range of loading applied, the measured changes in strain, after correction for local bending effects, gave longitudinal heart-of-plate stress, at places clear of stress concentrations, in fair agreement with simple beam theory.

2. The apparent strains measured over base lengths covering several frame spaces were sometimes higher than the heart-of-plate strains over short base lengths due to the axial movement caused by bending of the plating. This effect was observed particularly on the second deck, tank top and outer bottom.

3. In the regions in which bending of the plating was noted, there were concentrations of heart-of-plate stress at the longitudinal stiffening members.

4. The internal moments of resistance computed by summation of the stresses agreed with the corresponding external bending moments of 120,000 tons ft hogging and 80,000 tons ft sagging to within 3% and 6% respectively.

5. The assumptions adopted in the calculations of vertical deflections resulted in an underestimate of about 11%.

6. There was no evidence of permanent set or structural hysteresis over the range of bending moments applied during the experiment.

7. Local bending stresses were in some cases considerably in excess of the heart of plate stresses.

8. In panels which had considerable initial unfairness local bending stresses up to 11 tons per sq in were observed.

Miscellaneous Cycles

9. The logitudinal stresses due solely to change in trim were small. The maximum observed increase of stress for a trim of 29 ft did not exceed $^1/_2$ ton per sq in.

10. The maximum shear stress due to a torsion moment of 6890 tons ft was about 0.1 ton per sq in., and the corresponding longitudinal stresses were generally less than 0.2 ton per sq in. No angular deflection was detected.

NOTE—The evidence from Reports R9, R10 and R11 indicates that this torsion moment is unlikely to be exceeded at sea.

11. A change of 1375 tons in shear force produced maximum measured changes of 0.7 ton per sq in. in longitudinal stress, and just over 3 tons per sq in. in shear stress. This latter value is in good agreement with that given by simple beam theory. The maximum shear stress occurred near the calculated neutral axis.

12. Stresses due to change of 12.5 ft in draught were chiefly due to bending of the transverse members in the section. The greatest heart-of-plate stress, which occurred in the outer bottom plating, was 2.4 tons per sq in. in the transverse direction.

13. Local bending stresses in the side shell resulting from the increase of hydrostatic pressure associated with an increase of 12.5 ft in draught reached 2.8 tons per sq in.

14. The longitudinal stresses due to the horizontal bending moment were generally in agreement with simple beam theory, except where there was considerable local bending.

15. The horizontal deflection due to the horizontal bending moment was about 15% greater than that predicted by the simple theory, in which the effect of deck openings was ignored.

Structural Details

16. The concentration factor for the surface stress in the deck plating at a corner of No. 3 hatchway, was found to be not less than 2.8 which, however, includes effects of local bending.

17. The concentration factor for the heart-of-plate stress in the deck near the ventilator abreast No. 3 hatchway was 1.8.

18. Longitudinal stresses in the deckhouse side decreased rapidly with increase of height above deck and became insignificant at boat deck level.

19. Heart-of-plate stresses of 8 tons per sq in. were measured at the lower corner of the bulwark adjacent to the accommodation ladder recess with a hogging moment of 120,000 tons ft at the test section. Heart-of-plate stresses of 10 tons per sq in. were measured at one corner of the nearby washport.

20. The maximum stresses in the side frames in the Draught and Horizontal Bending cycles were 4 and 5 tons per sq in. respectively.

Foil Seam Welding

(*Continued from page 614-s*)

slower than for lap welding with machines without electronic control. Up to thicknesses of $^1/_{16}$ in. foil welding requires the same or slightly more energy than lap seam welding. The energy requirement is much lower for thicker material. For sheets 0.14 in. thick only 60% of the energy used in lap welding is required for foil welding. For sheets 0.032 to 0.14 in. thick and straight seams 8,10 and 12 ft long the welder capacity need be only 120, 150 and 180 kva, respectively.

The welds are of excellent quality. Gasoline tanks are tight under 3000 psi and the seams pass the Ericksen test. Tensile fatigue tests (0 to max. tension, 10,000 cpm) were made on soft steel sheet specimens $^3/_8$ in. wide, $^3/_{32}$ in. thick at the Zurich Federal Materials Testing Laboratory. The endurance limit of the unwelded sheet was 42,000 psi, while the welded sheet, unmachined, had an endurance limit of 38,400 psi. There is very little distortion in foil welding.

CORROSION-RESISTANT EVERDUR QUADRUPLES LIFE OF DEGREASING TANK

WELDING CHANNELS on side of tank with EVERDUR-1010 Welding Rods. Fabricated in 3 sections, this tank was welded and assembled by Storts Welding Company, Meriden, Conn.

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